SPACELIFT: SUBORBITAL, EARTH TO ORBIT AND ON-ORBIT

Overview

A vision for the future: In 2020, aerospace forces will be a reality. A notional composite aerospace wing, based in the continental United States (CONUS), would include a squadron of rocket-powered transatmospheric vehicles (TAV). These Black Horse[1] vehicles, derived from the Question Mark 2[2] X-vehicle shown in figure 1 and described later in this paper, will be fighter-sized airframes capable of placing an approximately 5,000 pound payload in any low earth orbit (LEO), or delivering a slightly larger payload on a suborbital trajectory to any point in the world. A Black Horse vehicle could accomplish either task within one hour of completion of mission planning, assuming that the payload was available at the base and the vehicles were on alert. When operating in support of a war-fighting commander in chief (CINC), the aerospace wing will thus have the capability to put mission-specific payloads on orbit (mission-tailored satellites) or on target literally within a few hours of identification of a need. Most missions--except some suborbital operational and ferry/deployment missions--will require aerial propellant transfer from modified KC-XX aircraft.

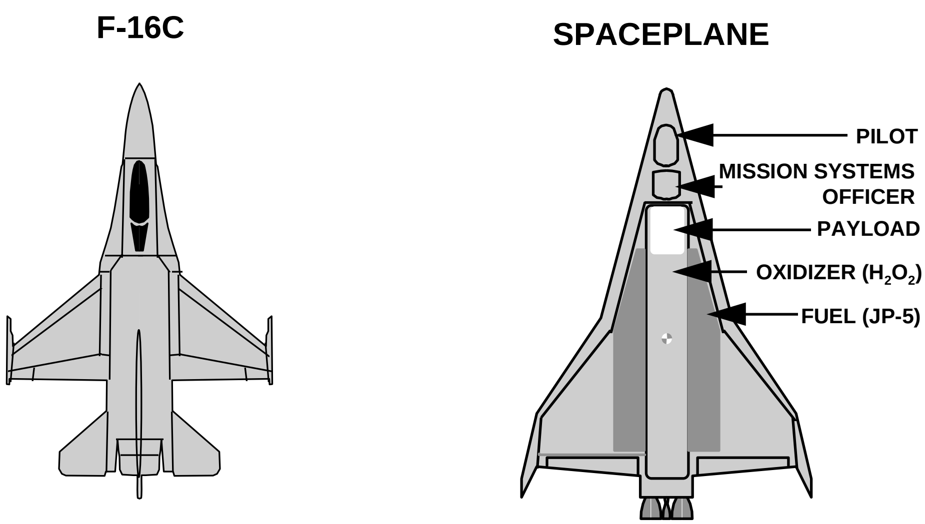

Figure 1. The First Black Horse TAV: "The Question Mark 2" X-Vehicle[3]
(Planform Comparison with F-16C)

These aerospace craft will use noncryogenic propellants--standard jet fuel and hydrogen peroxide--and will be designed for maximum logistics compatibility with the rest of the wing.

Maintenance and ground operations for the TAV will require no greater specialized skills than any other aircraft in the wing. TAVs returning from a mission would normally be serviced and returned to ready-for-flight status in less than a day, and could be surged to fly multiple missions per day if necessary. If tankers were prepositioned in theater, TAVs could also fly high priority global cargo delivery missions.

To fully exploit the TAV's capabilities, designers will adopt a new approach to satellite design, one that maximizes use of advances in miniaturization and modularity. Most space systems' designers thus take advantage of the vastly lower cost-per-pound to orbit (less than $1,000 per pound) that the TAV concept provides. Orbital payloads that are too large to fit in a single TAV can be designed as modules, launched in pieces and assembled on orbit.[4] Some high value satellites will be serviced, repaired, and modernized in space by space tugs which will move payloads launched on the TAVs to the mission orbit. With space launch and operations made routine by the TAV, multiple new uses for space systems will emerge, and the design cycle for new systems will be greatly reduced. Such systems will be less expensive, simpler and quicker to make, cause less concern if one does fail, and allow more rapid inclusion of emerging commercial technologies. The ability to orbit, upgrade or even retrieve dedicated, special purpose space support capabilities quickly and (relatively) inexpensively will dramatically change space operations. Satellites will perform navigation and most housekeeping functions autonomously. Central ground sites will monitor, update software, and assist these satellites in identifying repair requirements. Theater forces will task the mission payloads on these satellites directly by using deployable ground systems that require less lift into theater than 1990s communications/data display terminals. The result will be an array of space systems and operations that are fully integrated into global operations.

The description above is not science fiction. It is an entirely plausible outcome of the development program described in this paper. The initial reaction of many readers to the assertions above and the Black Horse TAV concept in general is that it is too good to be true, and that the claims are reminiscent of Shuttle or NASP promises. In fact, Black Horse is substantially different in concept from either of those systems, and the numbers and assertions in this paper are based on a preliminary but iterated design (i.e., several steps beyond a point design) performed by technically credible engineers. Although this paper does not present all the details of their efforts, some additional information on who did the design work, what methods they used and what assumptions they made is included in the attachments; references are included in the footnotes. Following a brief discussion of the current lift problem, later sections explain the steps needed to produce operationally effective TAVs and the associated capabilities.

The United States must have assured and affordable access to space to expand or even sustain space operations. This means being able to place useful payloads in all relevant earth orbits with high probability of launch success and operation on orbit within hours instead of months or years. It also means the ability to operate flexibly in and through space to accomplish both manned and unmanned missions in support of US national and military objectives.[5] By almost any measure, the current US space lift (earth to orbit) capability is not sufficiently robust. Worse, it is not improving. Suborbital (operations through space) and orbital maneuvering capabilities are almost nonexistent. If the United States is to make full use of space in the next century, military planners must address these shortfalls.

This paper proceeds from the assumption that assured access to space is crucial for many reasons: to enable future innovative ways of supporting combat forces, to counter threats from unfriendly space-faring nations, and to create the conditions for a commercial market that may ultimately support and drive rapidly evolving space technologies. Numerous studies[6] and other white papers in the SPACECAST study[7] are available to support this assumption. Ultimately, expanded military, civil, and commercial use of space depends on assured and affordable access to space.

A review of the limitations of current launch systems suggests several specific problematic areas:

- Current systems have severely limited abort capability because of such things as their predominantly ICBM heritage and the use of solid rocket boosters.
- Use of disposable hardware, manpower intensive operations, and the design of US lift systems in general results in large recurring launch costs.
- There is little or no standardization of launch vehicles, their interfaces, spacecraft buses, or payload interfaces.[8]
- Tailoring rockets to fit payloads is costly, wasteful, and unnecessary.[9]
- Solid rockets and disposable hardware are generally not environmentally friendly.
- The current huge and highly specialized launch infrastructure (ranges, launch pads, personnel, etc.) causes expensive, lengthy, and unresponsive launch schedules. Unless an alternative is discovered, this launch infrastructure will be archaic well before 2020.

- Space launch and operations procedures are overly complex and nonstandard, requiring "white coat" specialists instead of "blue suit" operators.
- Launch operations are “serial” events. One payload and one (dedicated) launch vehicle are readied interdependently and step by step, a process that does not allow parallel preparation of spacecraft and launch systems for flexible launch scheduling.
- The US does not have a flexible, operationally responsive space launch system or the capability to reconstitute even a limited capability on orbit in response to a crisis or loss (deliberate or accidental) of any US space system.

This paper does not propose a new national space policy, a new space lift policy, or a “silver bullet” solution that provides unlimited or unconstrained lift. Rather, this paper proposes an alternative architecture of space lift and suborbital and on-orbit vehicle capabilities that will enable the country to perform new missions in space, provide a responsive and resilient space lift/operations capability that is increasingly acknowledged as militarily essential,[10] permit an escape from the current vicious cycle of cost-weight-size-complexity-risk-delay that frustrates US government space systems, and offer the *potential* for future commercial exploitation that would not only result in vast new commercial opportunities, but would logically drive development of even better space system capabilities.

This paper proposes a spacelift system that can put usable payloads on-orbit affordably, has extremely high operational utility, is responsive, requires little or no specialized infrastructure, operates like an airplane, and has the potential to change the approach to space as surely as the DC-3 changed air travel. The paper also addresses potential suborbital missions that such a system would allow; discusses different ways of deploying, servicing, and redeploying space assets once they are on-orbit; and explains why this is desirable in some (but not all) cases.

If our nation has no desire for expansion in the use of space (either militarily, scientifically, or commercially) it can no doubt continue tinkering with existing launch systems and gradually refine procedures to gain small, incremental improvements in efficiency. This would commit the United States to an ultimately self-defeating cycle: the continuation of increasingly large and complex space systems, technologically obsolescent as soon as they become operational, and ever fewer yet higher-performance launch systems to put them on-orbit. The great risk, cost, and difficulty of replacement associated with failure of one payload during launch or while on-orbit demands increasingly burdensome and unwieldy oversight focused on ensuring that nothing can possibly go wrong. In other words, not only will a policy of business as usual not enable a breakthrough in the use of space, it may ultimately cause some existing uses of space to become unaffordable and unattractive.

The SPACECAST lift team recommends DOD proceed with a modified space development program that emphasizes the lift and on-orbit operations technologies highlighted later in this paper. This program must emphasize, above all else, increased operational flexibility and a concomitant reduction in specialized infrastructure. The top priority should be an X-program to prove the Black Horse transatmospheric vehicle concept. The entire cost of such a program would be less than $150M (using estimates discussed later in the paper). In comparison, a single Titan IV launch costs $325M. [11] This type of system, although not capable of meeting all lift requirements, offers great potential for a breakthrough in making space operations routine and introduces multimission capability. It stands above all other spacelift ideas evaluated.

The Capability and Its Relevance

The Missions

A TAV, like the airplane before it, has the capability to perform many different types of missions. This section discusses the possible uses of a TAV, as well as complementary auxiliary capabilities. The TAV concept described below is not intended to be all things to all people; in fact, SPACECAST explicitly recognizes that one system is unlikely to fully satisfy mission needs in every area. However, the TAV can perform a subset of missions across several mission areas. In this sense it is like the C-130: basically a transport airframe, but with AC-, EC-, KC-, MC- and other versions. SPACECAST believes that the TAV can improve on this by using modular, interchangeable mission modules (satellite or weapons dispensers, for example), so that the same airframe, flying very similar mission profiles, provides a flexible, responsive multimission capability. This capability, discussed in more detail below, provides tremendous leverage in achieving global reach, global power, and contributes to the overall SPACECAST concept of “Global View”.

The core of the proposed space lift and transportation architecture is an innovative space access capability that can operate like an air transportation system. The US space transportation capability of the future should include systems for moving payloads around, within, or through space (suborbital, orbital, or return from orbit). SPACECAST 2020 proposes pursuing a space lift development strategy that provides solutions to the country's most pressing problems, while encouraging (but not assuming) future quantum improvements in space transportation technology.

Space Lift. If launch of a satellite becomes a less complex, less time-consuming and less costly task, engineers can design spacecraft for shorter lifetimes with ease of upgrade or replacement. Shorter lifetimes would reduce fuel requirements, much of the on-board redundancy, and other elements related to design life. Designers could avoid much of the current cost redundancy and complexity, creating smaller, less expensive, more technologically up-to-date systems. Evolving toward such systems would make replacements easier to produce and launch, and the consequences of an on-orbit failure could be remedied as soon as a satellite was available. Satellites that must be large for physical reasons (e.g. optics like the Hubble telescope that do not use interferometry) could be designed modularly and assembled on orbit. To take full advantage of this capability, the US would have to revisit most of its basic assumptions about space operations, starting with the type of space lift system.[12]

It is important to note that a single system will not satisfy all needs, just as variants of a single airframe do not perform all air missions. A Black Horse type TAV will probably never launch a MILSTAR satellite. Also, transitional measures may be necessary to preserve operational capabilities until new technology systems come on line. This will undoubtedly include expendable launch vehicles in the near term. SPACECAST believes that the approach outlined below, while not addressing all spacelift problems, provides the maximum potential payoff approaching 2020 and for many years beyond.

Any proposed lift system must address the operational concerns and problems highlighted earlier. Specifically, to be militarily useful, a future lift system must be responsive (capable of launch on demand), highly reliable, able to abort a launch without destroying the vehicle (soft abort), resilient, flexible, logistically supportable, and easily operated. An overriding concern for all users—military, civil, or commercial—is that the system be affordable. These factors can be difficult to translate into specific numbers, so rather than set quantitative goals, this paper will seek a system that offers a recognizable qualitative improvement in the launching of payloads into space. Later sections of the paper describe the Black Horse TAV concept in some detail, using numbers from the initial design. These numbers show the capabilities of an X-vehicle designed with current technologies, and should not be seen as the upper limit of the concept's capabilities.

<u>Force Application Mission</u>. A version of the TAV contributes to our national military strategy by allowing the United States to rapidly respond worldwide to future threats with overwhelming offensive firepower. The system described in this section provides the National Command Authorities (NCA) and the CINC the ability to accomplish strategic-level effects within approximately an hour without using weapons of mass destruction. Rapid vehicle recovery, rearming, and re-launch on subsequent missions allow the CINC to continue the offensive through decisive follow-on attacks, thereby reducing the effectiveness of enemy interference with reconstitution and recovery attempts. The effects achievable by this vehicle have the potential to escalate the pace of war fighting beyond SPACECAST's projection of future threat capabilities. The system capitalizes on three specific offensive advantages:

- Speed and surprise. The greatest single advantage of this weapon is surprise. Strategic surprise results from the ability to strike enemy targets at any depth with little or no warning. Because kinetic energy multiplies the effects of any weapons delivered from a suborbital trajectory, the weapons themselves can be small (e.g. brilliant micro-munitions) and potentially a single vehicle can simultaneously strike a large number of targets. Operational surprise results from the rapidity of the completed attack, which may be timed to catch an adversary in the process of deployment or employment of inadequately prepared forces. Tactical surprise results from a variety of suborbital profiles these vehicles can use to exploit gaps in an enemy's defense. The speed of the system--the ability to put force on target anywhere in the world in a matter of minutes--also converts the global reach of the system into a form of "presence" which does not require constant forward deployment of forces.

- Mass, economy of force, and persistence. This concept can rapidly complete a multi- (perhaps even multithousand) aimpoint strategic attack with a small fleet of appropriately armed TAVs. The exact number will depend on vehicle payload capacity, final weapons designs, and cost. Rapid revisit times allow continued pressure on the enemy. The concept also contributes to solving the current concern of handling multiple major regional contingencies, since the surge rate of the weapon system should allow destruction of at least two widely-dispersed regional opponent's key centers of gravity within several days. Finally, the simultaneous presentation of thousands of small reentry vehicles to a surprised and defensively helpless adversary will likely overwhelm the enemy, thus ensuring the success of our nation's objectives.

- Synergy. The vehicle's ability to employ a variety of weapons allows tailored effects to prepare the battlefield for other weapons systems or to act as a force multiplier allowing ground, air, and sea forces unimpeded access to the battlefield to accomplish follow-on missions. Results can also provide synergistic effects for other national instruments of power.

On-orbit Operations Mission. Putting things on orbit (into low earth orbit in particular) does not always satisfy operational demands. Some satellites must be lifted to higher orbits, and some key space assets may require redeployment from one operation to the next (alter orbits). Missions to retrieve high-value assets for repair or upgrade (remotely on orbit, at a space station, or back on earth); to resupply space platforms with things like fuel, food, or weapons; or even to collect space debris and "dead" satellites from highly populated orbits are also possible.

As a result, the US may need a system for transportation between low earth orbit and other orbits. This is essentially an extension to concepts already studied by NASA and DOD. SPACECAST believes that these type of systems complement any lift concept, permitting either larger payloads for a given booster or a given payload to be launched on a smaller system. For the TAV concept, postulation of a separate on-orbit transportation system opens up additional missions, but it is not a requirement for the TAV to perform the basic missions described in this paper.

The Vehicle

Design of a vehicle to accomplish multiple missions is seldom easy. The history of the F-111 serves as a strong warning, as do our nation's so far unsuccessful efforts to accommodate all space users' launch requirements on a single vehicle.

The critical factor in aerospace vehicle design, as in air and space, is ensuring that the mission profile (range, maneuverability, type of payload, etc.) and the performance requirements (speed and amount of payload among others) of the proposed multimission vehicle are compatible. If they are, increased operational flexibility and cost savings through common logistics and operational procedures become possible. The SPACECAST team believes that this is the case with Black Horse vehicles for both the launch of spacecraft and the suborbital delivery of weapons or cargo. As mentioned earlier, the C-130 is a good analogy in terms of design philosophy: simple and as rugged as possible, not necessarily the highest performance system, but inherently capable of multiple missions.

Spacelift Options. The size of the payload put into orbit by a launch vehicle should not drive the launch system design. In fact, small spacecraft have many potential advantages, mentioned at the beginning of the paper. Cost-per-pound to orbit should be a key measure, and if the cost is low enough, almost any mission payload can be repackaged to fit a smaller launch envelope, or accommodated on several launches if need be. Those payloads that absolutely must have a specific size launch vehicle will probably never be affordable, although overriding national security concerns may still require their launch.

The strategy advocated--reducing payload size for a system that produces low operating costs--rests on four assumptions. First, the technology that drives space payloads (sensors, electronics, software, etc.) is advancing rapidly and even accelerating. This puts large, complex satellites (because of their long design and build cycles) more vulnerable to obsolescence on orbit and favors an approach that regularly places more up-to-date systems on orbit. Second, these same technological advances increasingly allow more capability to come in smaller packages: modularity, interferometry, bistatic radar techniques, and other technologies may even allow things traditionally seen as requiring large monolithic platforms to be put in space incrementally and either assembled on orbit or operated as a distributed system. Third, economies of scale have proved elusive in space systems. Large boosters are not appreciably (an order of magnitude) more cost effective (dollars per pound on orbit) than small boosters, and no projected demand or incremental improvements will significantly (again by an order of magnitude or more) reduce the cost of current boosters. Finally, military space operations will be increasingly subject to fiscal constraints; many national security requirements may no longer justify performance at any cost.

Even making these assumptions, there are several possible alternative systems, most of which are familiar. These include Pegasus, Taurus, other light expendable launch vehicles, converted sea launched ballistic missiles launched from sea-based platforms, hybrid (mixed solid-liquid propellant) rockets (also expendable), a variety of reusable vehicles from National Aerospace Plane (NASP)-derived systems to DC-X-derived single-stage-to-orbits (SSTO) and carrier-orbiter concepts like the German Sänger, Boeing’s Reusable Aerospace Vehicle (actually a trolley-launched system), and even cannon or railgun launch. A new idea with potentially greater promise is the air-refuelable, rocket-powered Black Horse TAV.

Table 1 is a comparison of several different launch systems that offer at least the potential for a qualitative improvement in space launch. Consistent with the philosophy outlined above, it does not include heavy-lift systems. A more complete description of the capabilities and assessment of these systems is in Attachment A. The Black Horse concept is described in more detail below.

Table 1.

Qualitative Launch System Comparison

System / Capability	DC-X SSTO	Black Horse	Pegasus	Taurus	Sea Launch	Gun Launch
Responsiveness	Good	Excellent	Good-Ex	Poor-Good	Poor-Good	Excellent
Flexibility	Good	Excellent	Fair	Poor	Fair	Poor
Soft abort	Fair-Good	Excellent	None	None	None	None
Resiliency	Fair	Good	Fair	Fair	Fair	Good
Logistics	Fair	Good	Fair	Fair	Fair	Poor
Reliability	Unknown	Unknown	Fair	Fair	Fair	Unknown
Ease of operations	Good	Excellent	Fair	Fair	Fair	Fair
Environmental	Excellent	Good-Ex	Poor	Poor	Poor	Fair-Ex
Cost (lbs to orbit)	Good-Ex	Good-Ex	Poor	Poor	Poor	Excellent

Which Kind of System is Best? Most of the alternative systems listed above actually do not offer a qualitative difference in the launching of satellites. Pegasus, Taurus, other expendables, and hybrid rockets fall into this category. A qualitative difference is important because even the most ambitious recommendations for improved conventional (expendable) boosters do not offer more than a 50 percent reduction in cost-per-pound to orbit,[13] and in most cases still rely on antiquated range support systems and to a lesser extent launch procedures. Small expendables, though more flexible and more operationally effective than large boosters, typically cost even more per pound to orbit. In making an eventual system acquisition decision, planners will have to carefully compare the life cycle costs of reusable systems with that of mass produced expendables; such a comparison is beyond the scope of this paper. It is worth mentioning, however, that one of the hidden costs of expendable rockets, particularly those using solid propellants, is environmental. Although difficult to assess, adverse environmental impact may be an overwhelmingly negative factor in future mass use of small expendable launch vehicles.

Cannon/railgun systems may be attractive in terms of cost-per-pound to orbit, but have some severe limitations. Payloads must withstand accelerations of 1000 Gs or greater (this does not facilitate building less costly satellites with fewer constraints on the use of commercial parts), and the US would become more, not less, dependent on specialized infrastructure. Barring a revolutionary advance in propulsion technology (which is as unlikely in the next 20 years as it is unforeseeable), SPACECAST believes that fully reusable lift systems integrated with mainstream aerospace operations offer the best hope for qualitative change in spacelift.

Problems With Reusables and General Design Goals. From basic intuition through the justification for the space shuttle to the most recent studies[14], fully reusable systems offer the greatest operational flexibility and potential cut in launch costs. Three problems continually recur: First, how to build a system that is completely reusable and has acceptable performance; second, how to justify the nonrecurring costs (infrastructure investment as well as hardware development) to get the eventual benefits of lower recurring costs; and third, how to reduce recurring costs to the point where an eventual payback can be expected. The space shuttle's problems in these areas and others have disillusioned people, but a radically different design may finally vindicate the reusable launch system approach.

The problems with fully reusable launch vehicles may have their basis in misplaced attachment to old paradigms of space systems (i.e. at least 20,000 pounds of lift capacity are needed to place useful payloads in orbit). The reason for this is twofold: first, it reflects satellite design assumptions that do not account for advances in miniaturization and modularity (i.e. what has become possible) and second, it assumes that payload size is the primary determinant of a launch system's utility (as opposed to, say, cost-per-pound of payload in orbit, or the ability to launch on extremely short notice). This drives performance to the edge of the envelope, creates tremendous development costs and dependence on immature technologies, usually fails to address operational implications sufficiently, and produces huge specialized infrastructure requirements that further drive up recurring and nonrecurring costs. These crippling problems can be overcome if designers challenge the old assumptions about space lift.

Space authorities have now acknowledged the negative relationship between trying to get the maximum number of pounds of payload onto a given rocket and cost and reliability.[15] Further, as discussed above, the vicious cycle of large satellite design and the opportunities provided by miniaturization and other advancing technologies argue in favor of smaller, standardized satellite designs.[16] Finally, military space authorities have expressed frustration with the "custom rocket" approach that comes from attempting to squeeze every last ounce of lift out of a given booster.[17] The time is ripe to design an operationally sound launch vehicle--one that utilizes existing, common infrastructure, can be maintained by well-trained high school graduates, and can be operated by well-trained non-scientist college graduates--first, then build payloads to fit it.

Development costs and dependence on immature technologies are linked to the performance issue. Because performance requirements are so high, only exotic fuels, engines, or design concepts can possibly meet them. As a result, billions of dollars in research and development are required to validate (and sometimes invent) the enabling technologies. All too often the success or failure of a given approach cannot be determined until the system is actually built, and even a prototype incorporating many advanced technologies may be prohibitively expensive. As an alternative, SPACECAST proposes an affordable X-vehicle development program that has clear near term military relevance and traceability to an operational system.

Failure to take into account the operational implications of a launch system—not just the launch crew but the support infrastructure for such things as fueling, maintenance, logistics, or basing—has been crippling in terms of cost and the eventual utility of systems. NASP-derived and two stage (carrier vehicle and space plane) concepts seem particularly vulnerable to this shortcoming, although they still represent an improvement over the huge, archaic, expensive, inflexible and manpower-intensive procedures required for current lift systems.[18] From the start, operational and infrastructure considerations must be given top priority. Space operations must become as routine and non-exotic as air operations.

Toward a New Type of Lift System: The "Black Horse" Transatmospheric Vehicles. To address these concerns, suppose that maximum performance (in terms of specific impulse for rockets) is not necessary or even desirable. This permits consideration of noncryogenic propellants, which offer several advantages. If these propellants are sufficiently dense, a workable lift system can be designed. The British did so with the Black Arrow and Black Knight programs using 1950s technology. This is because factors such as a reduction in tankage volume (hence rocket empty weight), a decrease in engine complexity, and an improved engine thrust-to-weight ratio make up for much of the (propellant) performance loss. Figure 2 shows how propellant density affects vehicle internal volume requirements. Interestingly, one of the most attractive combinations of noncryogenic propellants is jet fuel (nominally JP-5) and hydrogen peroxide.[19]

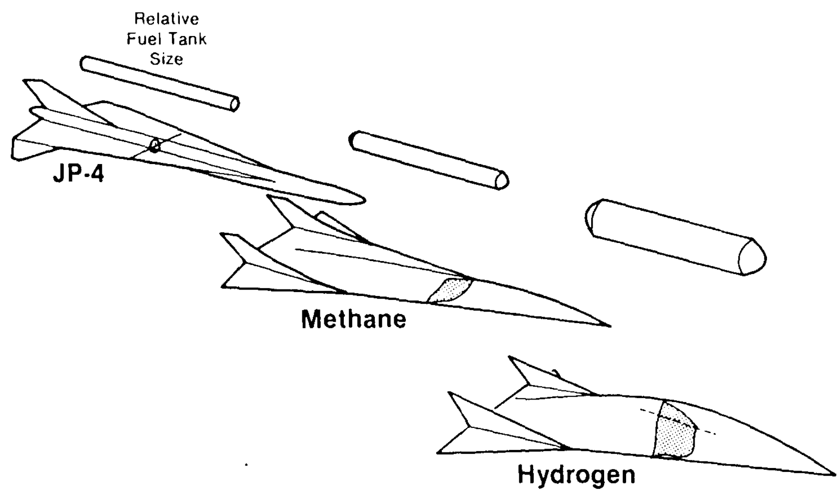

Figure 2. Notional Vehicle Cross Sections for Different Fuels[20]

The real attraction of this propellant combination is in the operational arena. The propellants are easily available (hydrogen peroxide is commonly sold for industrial uses at 70 percent purity; vendors could provide higher purities, or the commercial product could be refined on-site), storable, and pose no significant logistics problems. Rocket engines using these propellants also have excellent reliability histories, both on the Black Arrow and Black Knight programs and on the NF-104D research aircraft. The NF-104D program started such an engine (using JP-4 and H_2O_2) at least two times on every flight, experienced no rocket-engine-related emergencies during 11 years of operation, and was serviced and maintained with “essentially conventional maintenance procedures and normally trained personnel.”[21] Storage and handling of high-purity H_2O_2 is not inherently dangerous, and requires primarily discipline, not extensive safety equipment.[22] The Black Arrow and NF-104D programs routinely used 85-90% pure hydrogen peroxide; there are no known chemical reasons why operations with higher purities would be any more difficult. Finally, servicing a vehicle that uses cryogenic propellants requires many more steps (and is thus much slower) than servicing a noncryogenic-fueled (such as JP-5 and H_2O_2) vehicle. Even on the DC-X SSTO demonstrator, which had ease of operations as a design goal, fully 80 percent of the preflight checklist items were cryogenics-related.[23]

If readily available and easily stored propellants are used, the only reasons why a reusable vehicle could not operate from any location would be specialized requirements for assembly/loading, launch, and landing. Although a vertical takeoff and landing system has advantages in terms of empty weight and choice of launch/landing sites (theoretically it only needs a small pad), the SPACECAST Lift Team believes a horizontal takeoff and landing system is a better near term approach.

There are many advantages to a horizontal takeoff and landing space launch system. First, there are sufficient airfields available for any conceivable missions.[24] Second, fuel supplies and logistics infrastructure (crew equipment, admin support, ground transportation, maintenance and other ground personnel) are already located at airfields. Finally, a horizontal takeoff and landing vehicle would almost certainly be more robust. Its advantages include a larger abort envelope, the ability to land with all engines out, and greater cross-range on reentry. Further discussion of this issue can be found at Attachment B. There is a performance penalty associated this approach (hence the DC-X design), but there is also an ingenious way to compensate for it--aerial propellant transfer.[25]

True SSTO vehicles must lift all the propellant they need to reach orbit from the ground. This in turn drives the gross takeoff weight of the vehicle (including the wing and landing gear for horizontal takeoff and/or landing), hence its size and the engine and structural margins needed for safe take off and in case of a launch abort. Much of this structure is dead weight long before the vehicle leaves the atmosphere (hence staged designs). To date, two design approaches have attempted to eliminate this problem for SSTOs: NASP, which is an air breather for much of its flight, and the carrier vehicle/space plane two-stage concept. Both approaches have numerous drawbacks.[26] However, if the TAV can be launched with minimum propellants, and then *rendezvous with an aerial refueler* to load the remainder of the propellants, a different, more flexible design is possible. The choice of noncryogenic propellants is essential here, and the properties of a JP-5-hydrogen peroxide engine in particular (H_2O_2 is almost twice as dense as jet fuel, and the engine operates at a 1:7 fuel: oxidizer mix by weight) make it attractive to consider transferring the bulk of the oxidizer after takeoff.

At least initially, designers have conceived the Black Horse TAV as a manned system. Without addressing whether or not a crew is or always will be necessary, designers have planned for a crew for these reasons: A crew is essential for the initial X-vehicle development program, although that same program could test technologies that would enable later unmanned versions (unmanned aerial refueling, for example); a crew is desirable for several of the suborbital missions described below; and a crew <u>may</u> be desirable for some operations in space. If the vehicle has an austere (U-2-like) cockpit and is not designed for long-duration orbital missions (as will almost certainly be true for the X-vehicles), the effects of loss of payload weight will be minimized. The issue of whether man-rating from the beginning causes unacceptable costs is not a valid concern, since this system is not a piece of long-range artillery (a raglan or an ICBM) converted for transport use. It is, essentially, a fast, high-flying aircraft with no greater risks to crewmembers than any other developmental system.[27] Further discussion of this issue is in Attachment C.

In summary, the Black Horse TAV is a new kind of aerospace vehicle concept. It is not a new version of the space shuttle or NASP, and explicitly contains design choices in terms of size, performance and mission profile to ensure that those experiences will not be repeated. Specifically, Black Horse is a small vehicle with low empty weight and low weight on orbit, factors that historically correspond to cost. Black Horse--at least the initial X-vehicle concept as described below--is designed around existing technologies and for full reusability (unlike Shuttle) and ruggedness at the expense of the highest possible performance. Any comparison to NASP is particularly inappropriate: aside from horizontal takeoff and landing, there is no similarity. Because of the airbreathing engine, the low density fuel and the requirement to fly hypersonically in relatively dense air, NASP required multiple technological breakthroughs in propulsion and materials. In comparison, Black Horse thermal and structural requirements are much less stringent.

The structure of the Black Horse was designed using standard aircraft practice: given the maximum propellant offload from a KC-135 tanker, an estimated structural weight (from the volume required to enclose fuel, crew, payload, etc) and assumed weights for payload, crew, thermal protection and other subsystems, a wing was designed to provide sufficient lift throughout the flight envelope. This design was then iterated to ensure internal consistency. The resulting design (see attachment G) has a relatively low structural mass fraction when compared to other orbital vehicles. This has two primary causes: first, the propellants are substantially denser than “traditional” rocket fuels, thus the enclosed volume of the vehicle and consequently the structural weight is low. Second, by transferring the bulk of the propellant once airborne, the designers have avoided the penalty of sizing the wing, landing gear and supporting structure for a fully-loaded takeoff. This technique results in a savings of 4,200 pounds for the landing gear alone[28], and essentially makes the concept possible. Critics of the concept have expressed doubts about the numbers, but others, including Burt Rutan of Scaled Composites, have no doubts about the technical feasibility of the structure. Indeed, Mr Rutan believes the structure could be made even lighter using composites, instead of aluminum as the designers assumed.[29]

Other structural issues include the design of the payload bay and the thermal protection system. Although the payload bay was not designed in detail, additional structure was assumed based on aircraft requirements for internal cargo or weapons carriage. A thermal protection system of blanket insulating material and carbon-silica carbide (for the nose and leading edges), with a weight of 1.1 pounds per square foot, was included in the design.

The baseline design is for a vehicle weighing 48,450 pounds at takeoff (and 187,000 pounds after aerial refueling) powered by seven rocket engines. Two engines suffice for takeoff and the full refueling profile, so are optimized for lower altitude performance; the remaining five provide the additional thrust necessary for global reach or orbital insertion.[30]

The performance of the engines and fuel (JP-5 and hydrogen peroxide) was estimated using NASA standard codes and incorporating losses from geometry, finite rate chemistry, viscous drag and energy release efficiency. This results in a specific impulse of 323 seconds for the low altitude engines and 335 for the orbital insertion engines.[31] In terms of thrust to weight ratio for the engine itself, the performance is no higher than what the British were able to obtain from the Gamma engines (using kerosene and hydrogen peroxide) designed and built in the 1960's; the designers believe that this is a conservative estimate of potential performance.

The final element of the design is the payload deliverable on orbit. This depends on several factors, but as a figure of merit, the designers chose a 1,000 pound payload in a 35 degree inclined 100 nmi circular orbit (due east launch from Edwards AFB from a refueling track at 40,000 feet and .85 Mach). This assumes, of course, that the TAV also goes to orbit; flying a suborbital trajectory allows a significantly greater payload (6,600 pounds) to be placed in orbit, even after the weight of an upper stage (a 4,765 pound STAR 48V) is subtracted. If weapons or cargo delivery is the goal, 5,000 to 10,000 pounds could be delivered on a suborbital trajectory to almost any point on the globe using the baseline design.[32] The designers believe that all these numbers can be improved through better engines, lighter dry weight, potential fuel additives, and finally, by increasing the size of the vehicle (if so desired for an eventual operational system). These alternatives are discussed in more detail later in the paper.

Design Requirements for Weapons Delivery. There are several alternatives for delivering weapons, including the TAV described in preceding sections, ICBMs, satellite basing, and intercontinental cannons. The SPACECAST lift team believes operational flexibility greatly favors the TAV approach. A more detailed discussion of this is in Attachment D.

An appropriately configured version of the TAV can perform both ground and space force application missions with near term technologies. Some key characteristics of the air-refuelable rocket-powered TAV that are particularly relevant are the ability to operate as flexibly and responsively as an aircraft (with similar operations, maintenance, and logistics infrastructures), its inherently low observable nature from most aspects (no inlets, blended surfaces), and its ability to conduct manned missions. The vehicle has the ability to exploit the advantages of space basing (low reaction times and high energy states) with far greater operational flexibility and additional defensive capabilities to survive the future threat. Although the ideas presented in this section were arrived at independently, this concept is not new. Several other studies recommended similar vehicles.[33]

The system must have specific characteristics to accomplish the force application mission. First, the vehicle must be able to launch from a quick reaction alert status. This enables short response times critical to any future weapon system's success. The Black Horse TAV is capable of fulfilling this requirement in large part because of its use of noncryogenic fuels.

Second, the vehicle must be designed to incorporate modular weapons systems sized to fit the payload bay of the TAV. This concept allows use of the vehicle for a variety of military missions from force enhancement through force application, thereby increasing cost effectiveness. The TAV should be hard-wired to provide necessary infrastructure requirements (for example, basic power and communication links) to the module while the module reports fault/degradation information to the operator or controlling computer on the TAV. Note that these interfaces would not be significantly different from those required to launch a satellite. The largest part of the necessary weapons delivery infrastructure should be designed, as much as possible, into the clip-in module and not the carrier vehicle.

The idea of weapon modules serves several purposes. With this approach, the vehicle is able to accomplish force enhancement missions until required for weapons delivery; in other words, it is rapidly reconfigurable for different missions. In addition, the weapons modules can be preloaded with "wooden rounds," stored until needed and then quickly loaded on the vehicle. Maintenance or upgrades can be accomplished on the ground-based weapons ensuring maximum reliability and capability. Finally, the module concept offers quick reloads, facilitating rapid turn-times and therefore sustainability. By analogy with current dispensing systems, the deliverable payload should be approximately 75 percent of the vehicle's total payload capacity.[34]

Third, for survivability and maximum offensive potential, the vehicle must have global reach from a suborbital flight path. Global reach provides operational flexibility while allowing the vehicle to launch and recover from secure areas. The suborbital requirement contributes to self-protection tactics and is explained more fully later. Additionally, since the suborbital flight path requires less propellant than orbital insertion, greater weapon loads than for orbital payloads should result. Since weapons will generally be more dense than spacecraft, this should mean that an efficient multipurpose payload bay design is possible. Again, the Black Horse TAV satisfies this requirement.

Fourth, the TAV must allow rapid turn-around to follow-on missions. This maintains the initiative and offensive advantage for the CINC and allows rapid follow-on targeting. It is unrealistic to assume the military will have enough vehicles to engage all possible target sets with a single mass launch. Actual requirements for turn-around times will depend on the number of vehicles, the payload capacity for each, the number of aimpoints, and the threat. Any attempt to fix a hard number in relation to these requirements requires some detailed operations analysis, but a 12-hour cycle rate seems a reasonable minimum design criterion. The TAV and associated aircrew-to-airframe ratios should meet this minimum requirement.

Fifth, the system should maximize the use of existing military infrastructure. This requirement is levied to allow launch and recovery from the widest possible number of bases. This provides some measure of survivability through dispersion and mobility. The TAV provides a limited solution to this requirement and is restricted only by airfield length/capacity and refueling support. Attachment B contains further discussion of the horizontal versus vertical takeoff and landing issues.

Sixth, the issue of designing this vehicle for humans is important only in the near term. Technology has not progressed to the state where a computer can replace humans in all operations, specifically those in unpredictable environments or in degraded equipment modes. The SPACECAST lift team recommends designing early vehicles for human operators. While this will result in higher weight and lower G capability (the latter is probably not an issue for typical mission profiles), a human operator allows for rapid, autonomous (in accordance with the commander's intent) decision making, while facing the technologically advanced threat of the twenty-first century. When the data base is developed and hardware and software technology is sufficiently proven, human operators theoretically could be removed from the vehicle. Virtual reality is not a solution in the interim. Communications links are vulnerable to an advanced enemy and could be jammed or exploited. Taken together, these all argue that human pilots and human systems operators will continue to provide significant advantages, at least in the near term.

Finally, payload size may be a limiting factor in some specific employment scenarios. SPACECAST believes that the Black Horse TAV concept offers sufficient payload potential to perform a number of militarily useful missions. As mentioned earlier, a TAV capable of putting itself and 1,000 pounds of payload on orbit can deliver significantly more payload on a suborbital trajectory; further, there is significant growth potential in the basic design (sizing the vehicle around the fuel offload from a tanker larger than the KC-135, for example) which would lead to larger deliverable payloads.

Weapons Options. Three classes of weapons are appropriate for this vehicle: kinetic energy weapons, high explosive weapons, and directed energy weapons. In general, all weapons should be palletized or containerized for maximum flexibility in switching missions and to allow incremental upgrades and maintenance while the weapons are in storage. The Force Application white papers discusses these weapon types in more detail. Some general thoughts are in Attachment E.

In summary, a TAV capable of employing modular military payloads provides the United States a sustained counterforce capability for use against a wide variety of targets defended by increasingly capable future threats.

On-Orbit Operations Vehicles

As mentioned earlier, the ability to maneuver transfer or maneuver payloads on orbit provides enhancements to any lift system. This section addresses some general issues, but does not assume the use of any specific vehicle design (for example, the NASA Marshall Space Flight Center STV) or associated operations concepts. In other words, SPACECAST is not advocating use of on-orbit operations vehicles to be tied to any specific satellite architecture. However, the Lift team does recognize that tradeoffs (i.e. is it better to repair/service/upgrade a particular satellite or replace it) will be an integral part of any decision to pursue on-orbit operations vehicles.

Two key issues are important to this concept: the utility of reusable on-orbit transportation systems and the utility of on-orbit satellite servicing and repair. With regard to transportation systems, a 1989 study by the Air Force Systems Command (now Air Force Materiel Command) Directorate of Aerospace Studies (DAS) identified two basic vehicle configurations or capabilities: an orbit transfer vehicle (OTV) for moving things from low earth orbit (LEO) to higher orbits, and an orbital maneuvering vehicle (OMV) for moving things around within a designated orbit and docking with and servicing satellites. This architecture is superior to the current approach (expendable upper stages and/or propulsion systems integral to the spacecraft bus) for several reasons. Expendable upper stages are, by definition and design, thrown away after use and become "space junk." More importantly, however, while their unit costs are less than those of reusable vehicles, reusable systems are "generally less expensive on a per mission basis" over their usable lifetime.[35]

The DAS study also addressed the issue of whether or not it is more advantageous to use an on-orbit transportation capability to service and/or repair satellites on orbit, or to continue fielding expendable satellites. As expected, there is no clear answer. On the one hand, the authors conclude that, "it is reasonable to believe that there will be future circumstances which offer cost advantages to repairable satellites."[36] On the other hand, the analysis was sensitive enough to the estimated characteristics of future satellites (e.g., mission duration, mass, cost, subsystem reliability, and launch costs) that the results were not conclusive for all satellites in all orbits. In general, satellite repair becomes more attractive as constellation size and satellite mass, cost, and mission duration increase, and as launch costs and satellite reliability decrease. It is much more attractive from a cost standpoint if satellites use modular, standardized/common subsystems. The utility of reusable on-orbit transportation systems for satellite servicing and repair in the 2020 timeframe depends heavily on the types and quantities of satellites in orbit at that time, as well as on the capabilities and costs of US launch systems. Given this paper's assumptions of increasingly capable small packages and the ability to put them responsively on orbit, it is not at all clear that repair or resupply of existing satellites are attractive missions. On the other hand, if smaller but more cost-effective launch vehicles make on-orbit assembly and fueling of larger satellites desirable, many of the technologies discussed below will be needed. Ironically, it is the present large satellite paradigm and its associated high cost-per-pound to orbit that prevents testing the on-orbit repair concept.

Operations Concept

Basic Transatmospheric Vehicle Operations and Orbital Lift. The TAV would be readied for flight at an aerospace base different only from an airbase by the H_2O_2 storage and first level maintenance equipment, all of which could be deployed; fueled with 100 percent of its JP-5 and approximately 7 percent of its H_2O_2 capacity; loaded with its payload; taxi and take off; rendezvous with a tanker and load the entire tanker's capacity of H_2O_2; turn to the correct heading; and depart for orbit. From push-back to orbit would take less than an hour.

Once its orbital mission was completed, the TAV would deorbit and return to its own or any other suitable base; again, a very short process. A suborbital mission would be similar, and there would probably be no need to refuel before returning to base. Turn-around time is somewhat speculative at this point (the X-vehicle program would answer this), but a preliminary look at the technologies (rocket engine, thermal protection, etc.) suggests it will be a matter of hours or no more than days at worst; unlike the space shuttle, the TAV would be designed so as not to require extensive refurbishment between flights. Two technical areas are the key to the ability to "turn" the TAV quickly: thermal protection and engines. For the former, the combination of the aerothermal environment (less stressing even than for the space shuttle due to Black Horse's low wing loading and deceleration high in the atmosphere) and advances in materials since the space shuttle was designed should make the design of a fully reusable system possible. For the engines, the AR-2 used on the NF-104D provides a baseline: it routinely operated with two hours firing time (and numerous restarts) between overhauls[37]; the Black Horse designers believe that an improved design could do better. Although one of the purposes of an X-program would be to test the limits of reusability of a TAV, SPACECAST does not believe there are any showstoppers here.

This concept will provide vastly increased flexibility and responsiveness in launching spacecraft and performing suborbital missions, tremendously reduced operations and logistics infrastructure compared to other lift concepts, increased reliability, suitability for manned flight, and significantly reduced cost of space launch. It also builds on a current military aviation operational strength of aerial refueling, which has been done hundreds of times a day, versus airborne separation of large manned vehicles, which has been done a few hundred times in history in developing a new space launch capability. A squadron of eight Black Horse vehicles, even flying only once per week each, would provide access to space hundreds of times per year, making space operations truly routine. A summary of developmental and operational considerations for Black Horse TAVs is in Attachment F.

A Threat-based System. Future threats to the United States will possess far greater capability to impact offensive operations than current threats. Several types of threats are possible: hostile threat satellites, ground and space-based directed energy weapons, intercontinental ballistic missiles, and third world nuclear weapons and other weapons of mass destruction. An armed TAV could negate future threats through a combination of countermeasures, tactics, and survivable basing.

First, the construction of the vehicle should include as many low observable techniques as possible. While today's low observable technologies will gradually lose their utility, they will force adversaries to confine defensive systems to particular (and therefore predictable) techniques. They have the further benefit of reducing the detection envelope of enemy acquisition systems and therefore making the adversary's targeting problem more difficult.

Second, on-board active defensive systems are possible with this system. By using a suborbital trajectory during the attack profile, a TAV may use such disposables as chaff, flares, towed decoys, and active defensive munitions to defeat threat weapon systems without contributing to hazardous space junk. The design of the operational TAV could also accommodate modular Electronic Counter Measure (ECM) systems, weight and power budgets permitting.

Third, the TAV concept permits surprise. Even if an adversary has spies operating in the vicinity of airfields, if commercial media satellites detect operations in progress, or if the enemy detects unusual launch activity, the specific aimpoints, axes of attack, and timing of the attack are less easily predictable. Launch to a single suborbital weapons delivery pass followed by reentry and landing compresses the time the adversary has to respond--especially an adversary without either space surveillance capability or intercontinental launch detection. The enemy has minutes to observe the mission, assess intentions, make the appropriate decision, get the defensive capabilities in place, and complete the intercept. Multiple, simultaneous, inbound trajectories compound surprise and the next two effects.

Fourth, the inherent flexibility of a TAV enhances unpredictability. Again, the single suborbital pass serves as an example. Since the vehicle starts from ground alert, the enemy cannot predict the mission's time over target. The capability of the vehicle to establish a variety of suborbital trajectories, as well as approaching the target from differing orbital planes, also confounds the adversary's predictive ability and may negate many of his defensive systems.

Fifth, a squadron of TAVs translates into mass. The United States will more than likely have a small fleet of these reusable vehicles. The ability to mass several vehicles from single suborbital passes at the time and place chosen by the CINC, allows the commander to overwhelm the enemy's defensive systems as well as concentrate the appropriate amount of firepower to achieve required effects. In the absence of great numbers of vehicles, the same mass effect is maintained through the ability of each vehicle to deliver a large number of weapons.

Sixth, standoff. This assumes an appropriate family of weapons with sufficient crosstrack (to the sides of the delivery vehicle trajectory) capability. With these, the vehicle can release its payload outside the range of many possible threat systems.

Seventh, mutual support. Several vehicles working in concert can use advanced countermeasures as well as suppress threats for each other. The clip-in module for one vehicle, for example, might be a countermeasures suite. The clip-in modules for other vehicles in a flight would be weapons.

Finally, TAVs can easily be based in a dispersed fashion. While threat systems will surely have the ability to find and target aimpoints in the United States by the year 2020, their capabilities can be reduced through dispersion of the TAVs to a wide number of bases, through mobile operations, and through good deception plans. (An enemy's problem would be compounded if a large number of commercial TAVs also exist.) Any attempt to force this system to consolidate operations at a single fixed location is unnecessary and should be resisted as it obviously provides the adversary a fixed, high-value target. Logistics concerns can be adequately addressed by designing a vehicle that shares existing aircraft infrastructure to the maximum extent possible.

In summary, the ability of the TAV to accomplish its weapons delivery mission from a single suborbital pass, while using both passive and active countermeasures, compresses the adversary's decision loop and results in increased survivability. The addition of low-profile basing complicates the threat's targeting problem and ensures fewer assets are risked to the adversary's efforts during strategic attack. This combination results in a survivable system able to fight in the high threat environment of the 21st century.

<u>On-Orbit Operations</u>. To a large extent, the type of operations performed on orbit will be determined by the capabilities that new vehicles provide, whether OTV, OMV, or TAV. Orbit transfer vehicles could reduce the need for upper stages on launch systems with a corresponding increase in the amount of payload delivered to orbit. Maneuvering vehicles could provide some repositioning or on-orbit shuttle capabilities, a function that would help make orbital operating bases (space stations) functional. Both of these vehicles will facilitate on-orbit maintenance and upgrades to extend satellite lifetimes and combat technological obsolescence.

Even the TAV has implications for orbital operations. Besides capturing satellites and returning them to earth, the TAV may prove the best way to change a satellite's inclination. Assuming it is not easier to launch a new satellite to the relevant orbit, the TAV could go to orbit without cargo (to conserve fuel), capture a satellite, reenter and perform an aerodynamic maneuver to align itself with the new orbit (perhaps in extreme cases even refueling again), then return the satellite to space. Although the Black Horse studies to date have not included calculations of the fuel required for on-orbit rendezvous, this is a potential mission if the vehicle does not go to orbit fully loaded; unlike shuttle operations, launching an empty vehicle would not be a cost-prohibitive operation.

Links to Other SPACECAST Areas

The concept of the TAV connects many of the SPACECAST white papers. The logistics area of space lift with a militarily capable TAV is now linked to the white paper on a Global View architecture. This combination uses the proposed architecture to identify and pass coordinates of critical targets to the TAV prior to its weapons release point, cutting the time from initial target detection to destruction to an absolute minimum. This ensures that the TAV uses the most effective targeting intelligence to gain the greatest possible strategic effects.

The Force Application paper discusses various weapons types and their suitability. The TAV offers a platform for their use with significant military advantages over other techniques such as satellite basing. System architectures mentioned are compatible with the weapons delivery vehicle concept. Finally, the Offensive Counterspace area benefits from a TAV-based weapons system which could allow use of directed energy weapons without the requirement of building, deploying, operating, and defending an orbiting "battlestar."

Other linkages include the ability of the vehicles described in this paper to support the "motherboard" satellite concept described in the Space Modular Systems white paper, and the utility of a Space Traffic Control system in accommodating both the TAVs as well as increased on-orbit activity. Finally, many of the concepts in SPACECAST depend heavily on improving and reducing the cost of access to space--the heart of the Black Horse TAV concept.

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Potential Technologies

Transatmospheric Vehicles

Although a working TAV in the form of an X-vehicle can be built with existing technologies (see Attachment G), there are several areas where improved technologies and/or supporting capabilities will enhance performance.

- Structures. The initial aerial refueled space plane feasibility study, no formal title,[38] concluded that using standard fighter aircraft design criteria and aluminum structures, an F-16-sized X-vehicle TAV could place itself, a crew and 1,000 pounds of payload into orbit. However, further analysis of structural requirements and application of modern design techniques and materials could significantly reduce structural weight. As mentioned earlier, Mr Burt Rutan of Scaled Composites believes this is within current design and fabrication capabilities. Since Black Horse is a single stage to orbit vehicle, every pound of dry weight saved is an extra pound of payload.

- Engines. The same study baselined an engine no more sophisticated or efficient than the one used by the Black Arrow/Black Knight program (1950s technology).[39] A modest development program could certainly improve on this level of performance (efficiency, thrust to weight ratio) while improving reliability and maintainability. For a further step, a hybrid engine such as a ducted rocket[40] (admittedly a separate development program) could offer both a performance increase and reduced noise; both potentially critical factors for widespread commercial use of TAVs.

- Propellants. Although the intent of the program is to stay away from exotic or hazardous materials, there are options to increase specific impulse without sacrificing operability. Some possibilities are fuel additives such as quadricyclene, denser hydrocarbons (JP-8 or 10 vice JP-5) or, in the far term, high energy density substances such as metastable fuels (discussed in the Unconventional Lift paper). As long as the fuel continues to meet operability and logistics concerns, this is an area with tremendous potential payoff. An increase of one second in specific impulse would increase payload on orbit by 128 pounds for the initial Black Horse design.[41]

- Thermal protection system. The feasibility study referenced above baselined DuraTABI (Durable Tailored Advanced Blanket Insulation) material which weighs 1.1 pounds per square foot for area (“acreage”) coverage and carbon-silica carbide (C/SiC) for the nose and wing, strake and rudder leading edges. Detailed aerothermodynamic reentry calculations may indicate a less stringent requirement for thermal protection than was assumed in the initial design, possibly allowing even an all-metal skin (Rene 41 or Iconel 617). On the other hand, retaining excess thermal protection, perhaps by applying more advanced thermal protection systems, could give the vehicle a larger reentry envelope and even more operational flexibility.

- Refueling vehicle. Designers sized the TAV around the maximum amount of propellant that a single KC-135Q could transfer. These aircraft are in the inventory and already have separate aircraft fuel and off-loadable propellant tanks. Thus they would require minimum modification. The availability of a modified KC-10 or large commercial aircraft derivative to offload H_2O_2 would greatly increase the potential size and payload of the TAV without significantly changing (except perhaps to reduce) the cost-per-pound to orbit. Although this is more a programmatic than a technical issue, there are potential areas for investment in higher capacity pumps and perhaps a dual-tube boom refueling system to transfer both fuel and oxidizer at once. Attachment G, which outlines a multielement X-vehicle program, addresses these and several other technology issues.

On-orbit Operations Vehicles

As mentioned earlier, on-orbit operations vehicles complement most lift concepts. These vehicles have distinct technology development, demonstration and validation needs, however; these are outlined below.

Technologies required to implement on-orbit operations architecture include high efficiency, reusable space propulsion systems. Cost, performance, and operational utility analyses are needed to select from among the various potential technologies. Candidates include conventional chemical, electric, nuclear, and solar-thermal propulsion systems. Issues to be addressed would include: power sources for electric propulsion concepts; radiation shielding, high-temperature materials, launch safety, and waste disposal for nuclear propulsion concepts; solar concentrator fabrication and high-temperature materials for solar-thermal propulsion concepts; and long-life performance/reliability demonstrations for all concepts.

The on-orbit operations vehicles will require robotics for docking, grasping, repair, and resupply operations and/or telepresence/virtual reality/artificial intelligence technologies in some combination for on-orbit operations. Planners need analyses to determine the extent to which humans must participate in repair/servicing operations. Considering the technologies expected to be available in 2020, planners need to know what tasks can be done only by human beings, what tasks can be done remotely with humans in-the-loop, and what tasks can be done autonomously. Artificial intelligence technologies could reduce the requirement for human-in-the-loop operations in circumstances where this would be difficult or present technical challenges. Again, further analysis is required.

Spacecraft design would have to change significantly to obtain maximum utility from the TAV concept. Docking operations would require some degree of spacecraft bus standardization. Refueling operations would require propellant feed system standardization. Such design approaches as standard spacecraft buses and standard, modular, miniaturized subsystems and interfaces would facilitate repair/upgrade operation. External structures like solar arrays and antennae might have to fold to withstand the accelerations associated with high impulse spacecraft maneuvers or to stow the spacecraft in the bay of a TAV for redeployment. It is important to note that many of these changes will happen with or without the development of on-orbit servicing. They are driven by the need to reduce the costs and timelines associated with the earth-to-orbit segment of the transportation system.

OTVs may need supporting "bases" in certain critical locations. For transportation to high-altitude, low-inclination orbits, unmanned coinclination platforms in LEO would serve as cargo transfer and jumping off points for OTVs. Orbits containing large numbers of higher-cost satellites or fewer extremely expensive satellites would require co-orbital unmanned platforms where OTVs could transfer payloads to OMVs for final orbit insertion or docking/repair.[42]

Near Term Technologies and Operational Exploitation Opportunities

Transatmospheric Vehicle

Designers can use existing and proven technologies--aluminum structure, DuraTABI thermal protection--to develop and fly an X-vehicle to demonstrate the feasibility and operational utility of the Black Horse. As an interim step (discussed in more detail in Attachment G), existing AR-2 engines could be used to fly the vehicle through all of its atmospheric flight profile, testing handling, formation flying, refueling and suborbital trajectories, while a concurrent engine development program produces the higher performance engines needed to reach orbit. The basic concept is for a crewed vehicle approximately the size of an F-16 but with only 70 percent of its dry weight that could take off from and land on virtually any runway, load the bulk of its propellant (all oxidizer) from a KC-135Q (or T) tanker at approximately 40,000 feet and Mach 0.85,[43] and then carry out an orbital or suborbital flight. An experimental program could allow testing of the TAV as the US has tested aircraft for decades, with a gradual expansion of the performance envelope to meet the necessary objectives.[44] Some other characteristics of the program are in at Attachment G.

The primary areas for design and development are the vehicle aerodynamic configuration, higher performance rocket engines, and the vehicle structure. The WJ Schafer and Associates and Conceptual Research Corporation study[45] indicates there are no technological roadblocks in this area, and a vehicle could be designed and tested with existing technologies, although there is room for improvement using advanced materials.

Areas that require some careful design work but no technological breakthroughs are thermal protection, the need to cycle landing gear through the thermal protective surface, and the use of structural composites. It therefore appears that an X-vehicle program could proceed *with existing technologies*.

- Cost. Although not the single driving issue in this study, several comparative estimates of a two-TAV, 100 flight (including orbital) X-vehicle program suggested that the military could conduct such a program for a reasonable amount of money. Using actual X-29 and X-31 cost data, the Question Mark 2 TAV X-program would cost about $78 million (M). A Lockheed Skunkworks program cost model yielded $96 M. The RAND Corporation Development and Procurement Costs of Aircraft (DAPCA) IV model gave a total program cost of $118M. Finally, a cost estimate by an Aerospace Corporation analyst came up with $120M.[46] Although these are rough estimates and a vehicle of this type has never been built before, the fact that differing methodologies independently came up with similar numbers is somewhat encouraging.

- Operational Costs. Initial estimates, using a cost model based on SR-71 actual expense data, suggest that a Black Horse type vehicle could place payloads into low earth orbit at a cost of less than $1,000 per pound (the model yields costs between $50 and $500 per pound depending on assumptions) with a per-sortie cost of around $260,000 and an annual operating budget for an eight TAV unit, with support, of approximately $100M. This model may be particularly appropriate because the operations of an air-refuelable TAV and the SR-71 would be similar in several ways, not the least of which is using the same tanker. The model includes and is sensitive to overhead costs (assumed to be the same as for the SR-71), number of vehicles and sorties, payload (assumed to be 1,000 pounds), and fuel costs. A key point to emphasize is that this system is not "cheap" to operate relative to most aircraft; in fact the numbers are comparable to SR-71 operating costs. The cost-per-pound to orbit, however, even under fairly pessimistic assumptions (smallest payload, relatively few flights, high nonflying operations cost), is still quite low compared to other launch systems. Perhaps this shows just how expensive our current space operations really are (at $10,000 per pound to orbit and up), and how large the potential for improving that figure is with reusable launch vehicles. Cost-sensitive basing schemes and logistics concepts such as the USAF's "Rivet Workforce" which consolidate maintenance skills could further reduce recurring operations and maintenance costs. The assumptions and a comparison of costs using different assumptions are at Attachment H.

On-Orbit Operations

There are several near-term programs that would expand our ability to provide on-orbit services. These include the Space Surveillance Tracking and Repositioning (SSTAR) experiment (formerly called the Electric Insertion Transfer Experiment, or ELITE), an Air Force-TRW cooperative research and development agreement, a potential flight test of the ex-Soviet TOPAZ nuclear reactor, and the Space Nuclear Thermal Propulsion program. These deal primarily with propulsion systems, but particularly in the case of SSTAR, also with supporting technologies such as navigation, autonomous operation, and potential mission-oriented payloads. Unfortunately, all of these programs have suffered funding setbacks and are on hold or in danger of cancellation.

Commercial Opportunities

Cheap, reliable transport to, from, and through space offers innumerable possibilities.[47] It is the enabler for everything anyone does in the future in space. All of the technologies and techniques described above have potential commercial application, but a prescription of their use is beyond the scope of this study. Instead, this paper highlights some of the opportunities they may create, and why a robust commercial space market is ultimately essential for government use of space.

- Implications for markets. Cheap spacelift is a market enabler that will open up the use of space for things not currently practical or even anticipated. Some obvious possibilities include the extremely rapid delivery of people and cargo from one point on the earth to another, while the ability to carry passengers safely and at a reasonable cost could open a new market for space tourism. Availability of a technology (or technologies) that enables the economical use of space will in turn spur development of a true commercial market for all things related to space flight and operations. This will eventually drive the real cost of access to and operations in space down even further as jet transport has done in the commercial aviation market.

- Implications for US manufacturers. US launch vehicle manufacturers, if they pursue innovative technologies with true market-creating potential, could find themselves in a globally dominant position, as the US aircraft industry did following the introduction of the Boeing 707 and the DC-8. Dramatic expansion of the market for space transport, which will not happen without dramatic reductions in the cost of space access, is also absolutely necessary if the US launch industry is to remain commercially viable. The alternative can be seen in the current US shipbuilding industry. As an increasingly inefficient and shrinking US capability, it is unable to compete with low-cost and/or subsidized foreign producers and stays alive only because of government subsidies.

Government support in the initial stage of development is vital. The market for space is not large enough to drive the kind of productive and creative explosion in space-related hardware that has occurred in electronics, for example. The main prerequisite for this market is missing--rapid, reliable, affordable spacelift. Government and the military, whose performance requirements for launch on demand are the most stressing now, must take the lead in this area and produce the technological/operational breakthrough that will enable expanded future exploitation of space and the development of a large market to unleash the powers of commercial development. Industry cannot and will not make the investments needed for such breakthroughs on its own. They face a similar market to that for air transport prior to the DC-3, while development of a TAV will require an effort like the effort to produce the first jet transports. Development of jet transports would not have been possible without government investment in jet engine technology and large aircraft (B-47, B-52), despite an already fairly large air transport market.

Summary

The core concept of this paper is the Black Horse TAV. The initial reaction of most people to the concept is, "It sounds great, but if it would really work, why hasn't anyone thought of it before?" There is no simple answer to this question. The United States did flirt with transatmospheric vehicles in research and X-vehicle programs, but decided in favor of expendable boosters because of a combination of materials limitations, engine performance requirements and other technical factors, coinciding with rapidly increasing satellite weights. It seemed that only large boosters could put the required payloads in orbit. The rocket community discarded noncryogenic propellants for similar reasons. The rocket equation dictates that noncryogen-fueled vehicles have a propellant mass fraction of about 95 percent; cryogens reduce this to about 90 percent. Since all the structure as well as the payload must fit in the remainder, vehicles fueled with noncryogens did not seem able to orbit useful payloads.

Since then, however, much has changed. Miniaturization and other technologies now allow smaller satellites to do more than they once could, while large, complex systems have become increasingly unaffordable. In other words, it is now possible to get away from the tyranny of the payload and think about designing a launch vehicle for operability and even cost first, then building satellites to fit it. In turn, by assuming a reduced payload requirement; adding 20 years of additional knowledge in materials science, aerospace vehicle structural design, and lifting body research; and by recognizing that the greater density of noncryogenic fuels compensates somewhat for their reduced performance, the outline of a TAV concept begins to emerge. The final key element is the aerial propellant transfer.[48] Putting air refueling together with the other elements--in many ways a classic example of what John Boyd calls "destructive-creative" thinking[49]--led to the Black Horse concept.

Black Horse vehicles have the potential to revolutionize the way the military (and perhaps eventually the commercial world) uses and even thinks of space. They are true aerospace vehicles, with tremendous operational implications. A first cut analysis indicates that not only is the concept feasible, but that it can be done with no new technologies. The time is now to perform a more rigorous and detailed design, then to press ahead with a Question Mark 2 X-vehicle program to validate the system.

Attachment A

Launch System Comparison

Responsiveness (time from request for launch to orbit)

- DC-X SSTO: good; deployment (if required) and fueling time major constraint
- Black Horse: excellent; could sit alert
- Pegasus: good-excellent given alert-type arrangement
- Taurus: poor-good depending on whether system is deployed
- Sea Launch: poor-good; could require significant time to get into position
- Gun Launch: excellent

Flexibility

- Select any orbital inclination
  - DC-X SSTO: limited by launch sites, available Δv
  - Black Horse: unlimited access; some payload decrease to high inclinations
  - Pegasus: unlimited access; some payload decrease to high inclinations
  - Taurus: limited by launch sites, available Δv
  - Sea Launch: unlimited access; some payload decrease to high inclinations
  - Gun Launch: severely limited by number of launchers

- Interface to multiple payload types (largely payload design dependent)
  - DC-X SSTO: excellent
  - Black Horse: excellent
  - Pegasus: good-excellent
  - Taurus: good; somewhat rough ride
  - Sea Launch: good
  - Gun Launch: severe payload design constraints

- Ability to carry out other missions (suborbital, retrieval, space control, man in space)
  - DC-X SSTO: excellent; flexible payload capabilities; reusable
  - Black Horse: excellent; flexible payload capabilities; reusable
  - Pegasus: fair-poor; limited payload types; expendable
  - Taurus: fair; limited payload types, rough ride; expendable
  - Sea Launch: fair-poor; limited payload types; expendable
  - Gun Launch: poor; substantial payload design constraints; one way missions

- Surge capability
  - DC-X SSTO: design dependent; to be determined
  - Black Horse: design-dependent; should have SR-71-like capabilities
  - Pegasus: limited to vehicles in inventory
  - Taurus: limited to vehicles in inventory

Sea Launch: limited to vehicles in inventory
Gun Launch: limited only by number of payloads and power

Soft Abort Capability

- DC-X SSTO: limited; single or multiple engine failure could cause loss of control
- Black Horse: excellent; engines-out landing capable
- Pegasus: none; destructive abort only
- Taurus: none; destructive abort only
- Sea Launch: none; destructive abort only
- Gun Launch: none; destructive abort only

Resiliency (return to operations following an aborted launch)

- DC-X SSTO: fair; better than most rockets if failure is not engine-related
- Black Horse: good; comparable to current aircraft operations
- Pegasus: fair; heavily dependent on knowledge of failure (no recovery)
- Taurus: fair; heavily dependent on knowledge of failure (no recovery)
- Sea Launch: fair; heavily dependent on knowledge of failure (no recovery)
- Gun Launch: good unless gun is badly damaged/destroyed

Logistics

- Requirement for unique/special infrastructure
  DC-X SSTO: fair; design will help, but some new facilities and equipment needed
  Black Horse: good; some infrastructure, but much extant and common with aircraft
  Pegasus: fair; needs carrier aircraft, stacking areas, range control
  Taurus: fair; needs deployment equipment, range control
  Sea Launch: fair; needs launch platform operations and maintenance
  Gun Launch: poor; massive, highly specialized new infrastructure

- Consumables/fuel: storage and loading
  DC-X SSTO: fair, cryogenic fuels, but designed for easy handling
  Black Horse: excellent; noncryogenic, readily available
  Pegasus: excellent: solid fuel requires no handling but must be inspected
  Taurus: excellent: solid fuel requires no handling but must be inspected
  Sea Launch: excellent: solid fuel requires no handling but must be inspected
  Gun Launch: depends on power source

- Maintenance issues
  DC-X SSTO: designed for relatively straightforward maintenance
  Black Horse: could be designed to best current aircraft practice; good engines
  Pegasus: not applicable; expendable

Taurus: not applicable; expendable
Sea Launch: not applicable; expendable
Gun Launch: specialized facility maintenance needed

Reliability

- DC-X SSTO: to be determined
- Black Horse: to be determined; should be good for engines at least
- Pegasus: fair; similar to other expendable rockets
- Taurus: fair; similar to other expendable rockets
- Sea Launch: fair; similar to other expendable rockets
- Gun Launch: unknown

Ease of Operations

- Range requirements/restrictions
    DC-X SSTO: slightly better than expendable staged rockets
    Black Horse: similar to aircraft operations; possibly some noise limitations
    Pegasus: similar to other expendable rockets
    Taurus: similar to other expendable rockets
    Sea Launch: similar to other expendable rockets
    Gun Launch: unknown

- Command and control
    DC-X SSTO: similar to current range operations
    Black Horse: like aircraft
    Pegasus: similar to current range operations
    Taurus: similar to current range operations
    Sea Launch: similar to current SLBM operations
    Gun Launch: like long-range artillery

- Launch crew requirements
    DC-X SSTO: excellent; designed for minimal manning and training
    Black Horse: good; similar to aircraft operations
    Pegasus: limited but highly skilled manning
    Taurus: limited but highly skilled manning
    Sea Launch: somewhat launch platform dependent
    Gun Launch: limited but highly skilled manning

Environmental Friendliness

- DC-X SSTO: Excellent
- Black Horse: Good to excellent; combustion cleaner, more complete than jet aircraft
- Pegasus: Poor: expendable, solid rocket exhaust
- Taurus: Poor: expendable, solid rocket exhaust
- Sea Launch: Poor: expendable, solid rocket exhaust
- Gun Launch: Fair to excellent depending on power source

Cost-per-Pound to Orbit

- Recurring
    - DC-X SSTO: good to excellent; somewhat speculative at this point
    - Black Horse: excellent; based on SR-71 operations model
    - Pegasus: poor; small expendables are the most expensive per pound
    - Taurus: poor; small expendables are the most expensive per pound
    - Sea Launch: poor unless only surplus equipment used
    - Gun Launch: excellent

- Nonrecurring (including development and test)
    - DC-X SSTO: fair; multiple prototype development needed
    - Black Horse: good for X-program; vehicles could be designed to cost
    - Pegasus: sunk cost; only future upgrade money required
    - Taurus: sunk cost; only future upgrade money required
    - Sea Launch: sunk cost except for platform modifications
    - Gun Launch: poor; significant facility development needed

- Confidence in estimate
    - DC-X SSTO: largely speculative
    - Black Horse: credible but requiring proof
    - Pegasus: certain
    - Taurus: certain
    - Sea Launch: fairly well known
    - Gun Launch: largely speculative

Attachment B

Horizontal Versus Vertical Launch and Landing

Characteristics of Horizontal Systems

Horizontal takeoff and landing vehicles require wings or lifting surfaces to provide necessary lift and control throughout portions of the flight profile. Additionally, horizontal takeoff and landing requires landing gear and appropriately stressed airfields long enough for takeoff and landing. This fixed infrastructure is vulnerable to attack and is a disadvantage of horizontal launch and landing systems, including conventional aircraft. The degree to which this is a problem, however, depends heavily on the assumptions about a system's use. In the case of a transatmospheric vehicle with the ability to achieve orbit, there is little if any requirement for forward basing. If basing is primarily in CONUS, a potential enemy who could target every suitable airfield would be able to target almost any basing infrastructure.

If a vehicle can achieve short takeoff ground rolls similar to those of fighter aircraft, a horizontally launched vehicle could operate out of present-day military or civil airfields. However, landing rolls may be a different matter. Such a vehicle may require a NATO standard fighter runway of 8500 feet.

Although horizontal takeoff and landing may limit the available operations sites to airfields, wings/lifting surfaces offer advantages in vehicle maneuverability (greater cross-range capability on reentry, for example). Also, alternate landing sites may be available throughout the mission profile for aborts or in cases where the intended landing site is not available due to weather or battle damage.

An additional element of operational flexibility concerns weather. A horizontal takeoff system can operate under the same weather conditions as an aircraft. Vertical systems like current rockets will have stricter limitations because they must fly through any weather above their launch site; this is not possible if there is precipitation, since vertical launch systems typically reach supersonic speeds while still in the weather, resulting in serious damage. The TAV proposed in this paper will be above most weather before going supersonic, and if necessary can maneuver around weather before or during refueling.

Finally, there is the issue of testing. Although the DC-X program has made a breakthrough in the testing of vertical takeoff and landing (VTOL) systems, years of experience with aircraft testing seem to argue that the horizontal takeoff and landing system would involve fewer unknowns and better understood procedures.

Characteristics of Vertical Systems

Vertical launch's greatest advantage is its small footprint. With little requirement for a fixed runway, friendly forces become less predictable to an aggressive, technologically advanced enemy. The best example of this was found in the Gulf War. The United States, with superior intelligence, command and control, and weapons rapidly decimated all of Iraq's fixed air and missile attack infrastructure. Only those systems that were mobile and dispersed survived. The most successful of these systems were the SCUD missiles which continued operations until the end of the war.

A mobile, vertical launch system may retain some of these operational advantages, though not if it is much larger than current mobile missile systems (there is the problem of bridges, tunnels, trafficability, etc.). The question becomes whether enhanced tactical mobility and the resulting increase in survivability is appropriate or necessary in light of the costs associated with the capability.

Hybrid Systems

The weight penalty associated with horizontal takeoff (size of wing, landing gear and support structure) can be reduced through vertical takeoff with horizontal landing--this is essentially what the shuttle does--while retaining some of the reentry and landing advantages. Black Horse, in contrast, achieves the same effect through aerial refueling. The disadvantages of the vertical takeoff horizontal landing (VTOHL) are that the wing, landing gear and associated structure are dead weight throughout all but the final few minutes of flight. This means, first, that the wing has limited utility for a soft launch abort (it’s not sized for the vehicle gross weight; part of the reason for the shuttle’s expendable bits); second, that the essential problem of vertical takeoff (needing to produce a greater than 1:1 thrust to weight ratio vary rapidly, which drives engine performance) is exacerbated by the extra weight, and finally, that there is little if any margin for error on the first flight (even if airdropped, as shuttle was), which makes the test program more complex and expensive.

Additional Considerations

Other arguments are occasionally raised in favor of vertical launch systems. Most of these are not relevant to the TAV concept discussed in this white paper, but they pose questions that deserve to be discussed.

1) *Few runways in the world have suitable length or weight capacity to handle a horizontal takeoff and landing vehicle in the multimillion pound gross weight class*. Any vehicle, vertical or horizontal takeoff, in this weight class will require specialized launch sites (as a minimum, appropriately stressed concrete surfaces). Huge aerospace vehicles have consistently proved to be costly, unwieldy and generally undesirable unless there is no other way to perform the mission. The TAV concept proposed in this paper is explicitly a product of avoiding gigantism and attempting to minimize the vehicle's takeoff weight.

2) *Horizontal takeoff and landing systems have a more severe sonic boom problem.* This argument is design dependent. If the vehicle is designed to cruise super/hypersonically in the atmosphere (like NASP), it may be a concern. The TAV proposed in this paper is rocket-powered and has no need to fly horizontally. In fact, the flight profile is strictly subsonic until commencement of the orbital/suborbital insertion burn, at which point the TAV basically rotates to a vertical aspect and adopts a trajectory similar to a conventional rocket (perhaps somewhat modified to take advantage of lift early in the flight). The sonic boom/noise problem is, if anything, less than that of a VTOL rocket, since the orbital insertion burn begins at over 40,000 feet vice sea level, and the vehicle goes supersonic at a higher altitude than a VTOL system.

Summary

The question of horizontal takeoff and landing versus vertical takeoff and landing comes down to the interconnected issues of engineering design and operational requirements. The landing gear and lifting surfaces of a horizontal system obviously result in a heavier empty weight, thus less payload. On the other hand, the VTOL system must have significantly more fuel on board to land, and it must take this to orbit in lieu of payload.

The need to operate from a runway imposes some operational limitations. On the other hand, lifting surfaces and the ability to operate like an aircraft offer increases in operational flexibility in other areas, and the number of runways available to a reasonably sized TAV combined with the system's range mean that a threat to all suitable airfields is only realistic in the most extreme scenarios. In addition, it is not at all clear that a VTOL system requires less infrastructure. A VTOL needs transport for the launch vehicle from its base(s) to a launch area. Fuel transport and storage, payload handling, maintenance, and other logistics functions must all be deployed with the VTOL system to make it work. The horizontal system, on the other hand, makes maximum use of existing infrastructure. On balance, it is our judgment that in the near term and for the missions envisaged by this paper, the horizontal takeoff and landing system is the preferable way to attain the global reach that enables global power.

Attachment C

Manned Versus Unmanned Systems

For years, unmanned aerial vehicles (autonomous or remotely piloted) have been technically possible and lately such vehicles have become more prominent. Cruise missiles, which blur the line between drone and aircraft missions (albeit one-way), have become relatively well accepted. At present, unmanned vehicles do not possess the operational flexibility (in terms of retargeting, alternate missions, etc.) of manned aircraft. On the other hand, manned aircraft are inherently more expensive vehicles, and may be unsuited for certain missions, because of the risk to or the limitations of the crew.

This study considers capabilities for 2020. It is entirely possible that by 2020 techniques such as telepresence, virtual reality displays, and communications links with increased security, reliability, and bandwidth will enable remote piloting of most missions. For a Black Horse type vehicle, remote piloting could include not only launch, payload delivery, reentry and landing (which obviously can be done now by unmanned systems), but also suborbital weapons delivery missions that do not require a human-in-the-loop, and even aerial refueling with a remotely piloted or a drone. The SPACECAST Lift Team agrees that these things are possible and may even be desirable, though there probably will still be missions (even in space) in 2020 where a human presence is advantageous or necessary.

The problem of getting there from here remains, however. In particular, for a Black Horse TAV, there is the issue of performing an aerial refueling operation of an unmanned vehicle, particularly of one with such different performance characteristics as a rocket-powered TAV. There is also a question of how well the performance characteristics of the vehicle can be explored remotely. Chances are that a manned X-program offers the most reliable way of conducting the initial tests. With the adaptability of the human in the cockpit (and a flight test engineer on board as well), well-established test and development procedures can be used. Starting with an unmanned vehicle would require development of at least some new test procedures in addition to the vehicle test program. These kinds of development plans would inevitably incur large delays in concept validation.

Another issue is the assertion that designing the vehicle for on-board human operators will impose unacceptable costs and performance penalties. This is not necessarily so. First, unlike conventional rocket designs that derive from missiles and are inherently adaptations of throw-away, one-way designs, reusable aerospace vehicles must "take care" of themselves. In other words, the vehicle must survive its flight, and the ways it does this are relatively easy to adapt to human requirements. For example, TAV space launch vehicles are unlikely to execute 50G turns or reenter like ballistic missile warheads. The former is unnecessary, and the latter imposes severe constraints on reusability. The primary issue for humans are reliability, nondestructive abort, recovery and landing, life support, and instrumentation. All of these except the last are inherent characteristics of Black Horse vehicles.

The issue of life support and instrumentation is mainly one of cost versus benefit. For a Question Mark 2 X-program, an austere cockpit (like the U-2) is certainly acceptable. With limited duration operations, oxygen, other consumables, and general crew equipment will be minimal. Instrumentation requirements are approximately the same between manned and unmanned X-systems, though the requirement for displays and controls in a manned system means some extra weight. The overall weight penalty (about 2000 pounds, according to the Black Horse initial concept study) associated with having two crew members aboard is significant, since much of that weight could otherwise be payload, but the goals of the program must be kept in mind. Given the unique nature and type of unknowns about this system, the X-vehicle should not be driven by maximizing payload.

On balance, operational TAVs may be unmanned, but this is an issue for cost and operational effectiveness analyses. We believe a manned X-program is the right way to start and is a prerequisite to exploring future unmanned options.

Attachment D

Weapons Delivery Vehicle Type Tradeoffs

Weapons Delivery Vehicle Versus Satellite-Based Weapons

The energy advantage inherent with space basing is equal for both weapons delivery vehicles and satellite-based weapons and is an advantage of both. The operational utility and survivability of the weapons delivery vehicle is superior to satellites as described below. Satellites have positioning problems and require constellations for guaranteed response times of less than one hour. Even a constellation of satellites requires sequential operations, and a significant delay incurs as each satellite orbits into position. The weapons delivery vehicle will have the ability to attack in mass and with similar first response times as a constellation.

Satellites are both observable and fixed in their orbits. This makes them predictable and vulnerable to the enemy's counterspace weapons. Any sort of disposable countermeasures and some active defense systems would result in hazardous space debris. A first strike directed against our weapons satellites could deny us their capability. The TAV weapons delivery vehicle operates in far less predictable suborbital flight paths which can take advantage of enemy vulnerabilities. The vehicle can use active countermeasures in a suborbital trajectory since any debris will fall back to earth.

Satellites are a fixed, obsolescing asset once in orbit. The onboard weapons failure rates increase over time and their capability will eventually limit the effectiveness of the system. Once a satellite is in orbit, its payload type is fixed allowing little operational flexibility, and once it expends its munitions it is useless until reloaded. These problems are not applicable to the modular weapons used with a TAV since they are stored on the ground and are available for maintenance and upgrade. The modular concept allows configuring the payload to match the target prior to each mission as well as rapid reloads following missions.

Weapons satellites also suffer from a legal and a political disadvantage. International agreements prohibit basing of nuclear weapons in space. Although SPACECAST does not propose using nuclear weapons, the basing of *any* weapons in space will inevitably raise a verification issue and may be viewed internationally as provocative. Politically, countries may resist space basing of weapons of any kind, whereas countries may accept delivery of weapons through space, especially by a TAV which is subject to positive control and recall throughout much of its flight. A satellite's main advantage is presence in those cases when a weapons delivery vehicle is unable or undesirable for use.

Weapons Delivery Vehicle Versus Intercontinental Ballistic Missiles (ICBM)

The prime advantage of converting surplus ICBMs is sunk costs. They are available and it seems like a waste to ignore the capability they might offer. The TAV and ICBMs have similar delivery capabilities for kinetic energy type projectiles. However, the ICBM has no capability to bring weapons back and would therefore be a poor choice for directed energy weapons in a counterspace role. In general, missiles offer less operational flexibility--basing, relocatability, deployability, targeting, flight paths, alternative missions, and payloads--than a TAV. In the potentially high-tempo world of the future, political and military environments could change rapidly. Once launched, ICBMs cannot be recalled, whereas TAVs can be recalled until weapons release, or can even go to orbit and wait for weapons release authority. Moreover, cooperative missile launch notification protocol may, in the future, make surprise less likely. TAVs are not included in such protocols.

Conversion of old ICBMs also raises practical problems such as the remaining life of the missiles and the permissibility of such a conversion under the Strategic Arms Reduction Talks (START) treaties. However, if these problems were overcome, a combination of ICBMs and the weapons delivery vehicle may offer an attractive long-term option to combine the cost-effectiveness of using paid for systems with the flexibility and sustainability of the weapons delivery vehicle.

Weapons Delivery Vehicle Versus Intercontinental Artillery

Intercontinental artillery relies on a fixed installation due to its size and is therefore vulnerable to a capable adversary. This vulnerability is minimized for the weapons delivery vehicle as explained in the defensive tactics section. Intercontinental artillery would also be limited in the number of trajectories available, unless the tubes/rails could be slewed to different azimuths.

Weapons Delivery Vehicle Versus Conventional Aviation

The purpose of the weapons delivery vehicle is not to replace the projected fleet of combat aircraft. It could become part of a future composite aerospace wing as described at the beginning of the paper. The TAVs advantages of speed, security, and lower vulnerability make it a valuable complement to existing conventional combat forces. Targets requiring large amounts of high explosive, loiter time, or visual identification will still be suited to conventional aviation.

Attachment E

Weapons Types for Suborbital or Transatmospheric Vehicles

Kinetic Energy Weapons

This class of weapons capitalizes on the destructive effects of a relatively small, hypersonic projectile impacting a target's surfaces.[50] These penetrators work best against hard surface targets that resist the projectile. This allows them to impart sufficient energy to the target to generate destructive weapons effects. Kinetic energy penetrators will require a wide range of sensor options for reliable target identification and guidance to precise aimpoints against fixed and moving targets under all conditions. Finally, penetrators should be developed in a variety of sizes to tailor weapons effects to a target and allow carriage of the greatest number of weapons per module.

High Explosive Weapons

High explosive options may still be necessary. High speed projectiles may require additional P_k because of accuracy or damage mechanism limitations (they might pass right through thin-skinned targets without causing sufficient damage). In these cases conventional high explosives can make up for the lost weapons effects. Additional devices for slowing projectiles might be necessary to allow independent search and targeting, mining, or for specific weapons effects. The SPACECAST team envisions a maneuverable reentry vehicle that both delivers the payload to the target area and controls the velocity prior to releasing appropriate high explosive submunitions.

Directed-Energy Weapons

Directed-energy weapons offer significant benefits but also have numerous disadvantages. The disadvantages center around high infrastructure requirements (power generation, pointing mechanisms) and propagation of sufficient energy through the atmosphere to target surfaces.

Infrastructure means weight. This problem reduces the weapons on a vehicle to a low number. The end result is fewer targets hit on a single pass. This limitation combined with energy loss to the atmosphere results in less than optimum performance against ground targets. Until these limitations are corrected, directed-energy modules should be used for the counterspace mission. This mission offers no energy loss to the atmosphere, disables targets with minimum space debris, and may allow multiple targeting of space platforms per mission.

Attachment F

Characteristics of a Black Horse JP-5/H_2O_2 Fueled Transatmospheric Vehicles

Development	Logistics	Maintenance	Launch
Available technology	JP-5/8/10	R&M design	Gross take-off weight
- engines	Commercial H_2O_2	Engines	Payload handling
- structure	- 70% to 98%	- reliability	Fueling procedures
- thermal protection	- purified on site	- lifetime	Preflight checks
- avionics	- mobile equipment	Avionics	Taxing
X-vehicle program	- resell byproduct	Landing gear	Takeoff roll
Incremental flight test	- easily storable	Thermal surfaces	Abort procedures
Verify procedures	Engines	Control surfaces	
Verify operations cost assumptions	- simple (relatively)	Composite materials	
Proof of concept	- spares required	Landing gear, doors	
Ability to crash build	- parts required		
	KC-135Q/T		
	- number needed?		

Refuel	Orbit Insert	On orbit	Deorbit
Take on 140,000 lb H_2O_2	Aircraft navigation system	Ground control	Communications
Rendezvous time	GPS receiver	- Air Traffic Control to Space Traffic Control hand-off	Criteria
- time to altitude	Integrated flight control computer	Communications links	- landing site
- fuel to altitude	Insertion setup	On-orbit fuel	Procedures
- monopropellant operations?	- latitude, longitude	- mission dependent	Flight path
Boom time	- azimuth	Payload deployment	Reentry loads
- refuel rate	- ATC clearance	Other missions	- thermal
Refueling procedures	Precise insertion	- rendezvous	- structural
- airspeed	- computer throttling	- assembly	Cross-range capability
- latch controls to tanker	Available inclinations	- capture/repair	
- via boom connection	-virtually any	- fueling	
Visual check by tanker		Endurance	
Ability to tank JP also?		- crew systems	

Recovery/Turn	Suborbital Operations
Landing	Missions
- dead stick?	- weapons delivery
- go-around capability?	- space control
Weather limits?	Range
	Fuel reserve
	- 2 suborbital flights
	- loiter time
	Payload?
	Tank at destination?
	- Operations Security

Attachment G

X-Program Details: Black Horse and the Question Mark 2

The goal of the X-program is to incrementally and affordably prove the concept, procedures and technologies associated with a noncryogenically fueled transatmospheric vehicle capable of air-to-air propellant transfer. This paper refers to this class of vehicles as Black Horse vehicles, the first of which would be called the Question Mark 2 to recognize it as a continuation of innovative air-to-air refueling demonstrations.

Analysis and Design Issues

The claims made for the Black Horse vehicle are based on preliminary design work done for the USAF Phillips Laboratory under the direction of Capt Mitchell Clapp, a flight test engineer, former TPS instructor, and the only Air Force "crewmember" qualified on the DC-X, who developed the initial concept. Aerodynamic and structural calculations were performed by Dan Raymer (Conceptual Research Corporation), the designer of the X-31, former Chief of Advanced Design at Lockheed and author of *Aircraft Design -- A Conceptual Approach*, using the RDS-Professional computer-aided design and analysis system, with weights estimated statistically using the Vought fighter equations. Aerothermodynamics estimates including reentry were done by Ed Nielsen, a former NASP engineer, of WJ Schafer and Associates. Rocket design was performed by engineers at WJ Schafer with over 80 years of design experience at Rocketdyne and elsewhere. Flight trajectory and parametric performance studies were done using NASA's POST (Program to Optimize Simulated Trajectories) software. The design has been iterated on a system level, and has been shown to be internally consistent. Key assumptions were: reentry using NASA HL-20 profiles (generated from the MINIVER and LAURA codes), which should have higher heat loads and transfer rates than Black Horse due to the latter's lower wing loading and deceleration high in the atmosphere; an all-aluminum structure; thermal protection and external materials using 1980 technology; and the size of the vehicle constrained by the maximum propellant offload . In short, while the design is preliminary, it was not done carelessly or by amateurs. The SPACECAST Technology Team, including AFIT, has reviewed the calculations and found no obvious errors, unsupportable assumptions, or improper methods.

The top priority before embarking on an X-program would be a rapid but thorough completion of the analysis and design effort. This would concentrate on four areas: a detailed reentry analysis to provide complete data for designing the thermal protection system, trajectory modeling to further refine the performance requirements for this particular design, a detailed structural analysis to include an evaluation of the possible application of composite structural elements, and rigorous engineering cost estimates to substantiate the assertion that an X-program could be done for close to $100M.

Basic Program

The basic X-vehicle program includes the building of two Black Horse TAV airframes, an appropriate number of noncryogenic rocket engines, and the conversion of at least one KC-135Q tanker aircraft to carry hydrogen peroxide. Testing would proceed along the lines of classical aircraft flight testing.

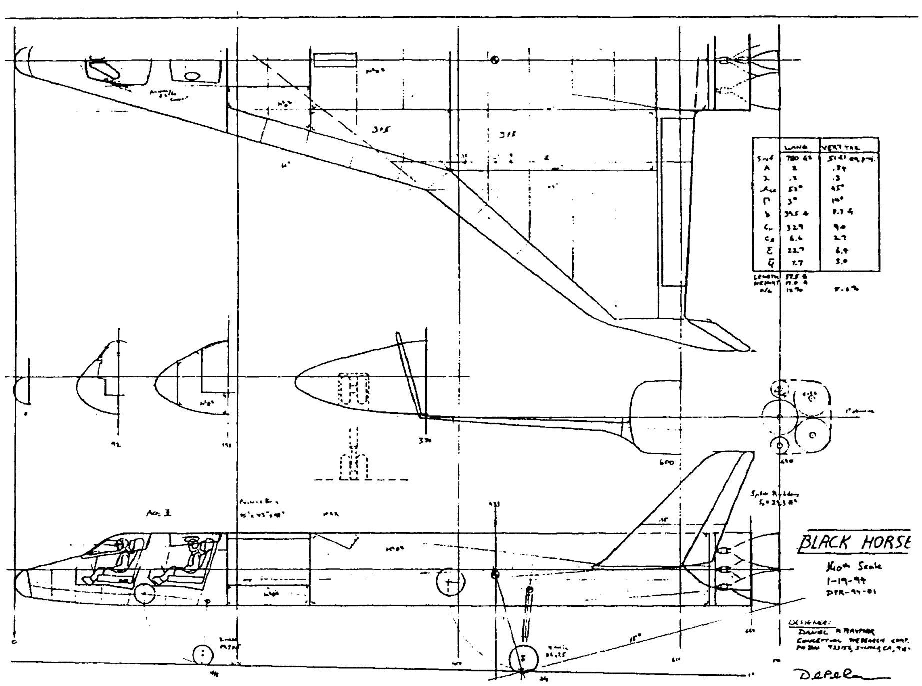
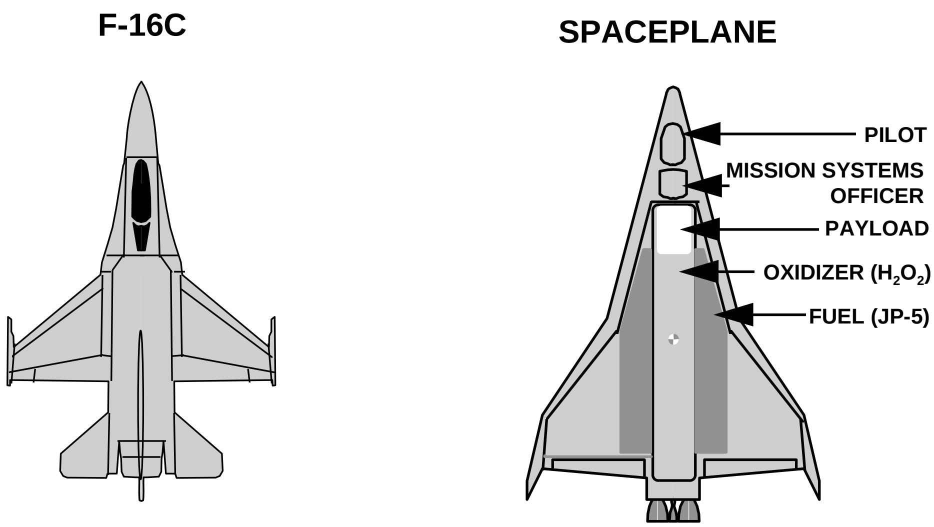


Figure 3: Black Horse X-Vehicle ("Question Mark 2") Engineering Sketch

The Vehicle. The initial design concept for the X-vehicle (shown in figure 3) was sized around the maximum amount of propellant (in this case 147,000 pounds of hydrogen peroxide, the oxidizer) that can be carried by a single KC-135Q. (Because the oxidizer is heavier than jet fuel and is burned at a 7:1 mixture ratio, this is the logical propellant to transfer.) This results in a vehicle that is 57.5 feet long with a 39.5 foot wingspan. The wing is a double-delta platform with a large strake blended into the fuselage and using two wingtip vertical stabilizers. As initially designed, the vehicle is approximately 8 percent aerodynamically unstable at subsonic speeds (about the same as an F-16), neutrally stable trans-sonically, and about 10 percent stable at hypersonic speeds. Gross takeoff weight is approximately 50,000 pounds (see Table 2 below). Propulsion is provided by seven rocket engines, two primarily for ascent and five main engines, the difference being the exhaust nozzles (the ascent engine nozzles are optimized for low altitude performance). Figure 4 shows a planform comparison to an F-16. Table 2 shows some basic vehicle characteristics.



	F-16C	Spaceplane	
Empty Weight	18,238	14,958	pounds
Max T/O Weight	42,300	48,452	pounds
Span	32.8	39.5	feet
Length	49.5	57.5	feet
Height	16.8	17.0	feet
Wing Loading (peak)	1200	550	lb/ft^2
Payload	12000	1000	pounds

Figure 4. Planform Comparison of F-16 and a Black Horse Vehicle[51]

Table 2

Estimated X-Vehicle Characteristics[52]

Empty Weight	14,958 lb
Gross Takeoff Weight	48,452 lb
Payload	1,000 lb
Takeoff Distance	2,500 ft
Tanker	KC-135Q
Propellants	JP-5/Hydrogen peroxide
Gross Lightoff Weight	187,000 lb
Crew	2
Ferry Range (unrefueled)	3,200 nm
Suborbital Radius	5,000 nm

Test Program. Testing would progress from engine static firings through high speed taxi tests to takeoffs, landings (powered and unpowered), and basic aerodynamic handling characteristics. When the envelope had been sufficiently expanded, formation flying with the tanker, initial hookup and finally propellant transfer testing could begin. In parallel with this, the other TAV could be conducting high-speed, high-altitude flights, to include ballistic trajectories, using the maximum amount of propellant that can be loaded on the ground. This will naturally be followed by increasing altitude suborbital trajectories following aerial propellant transfer; these tests will demonstrate not only boost phase but reentry performance. The test program will culminate in orbital flights, eventually demonstrating payload delivery. The thrust profile of an orbital mission is shown in figure 5.

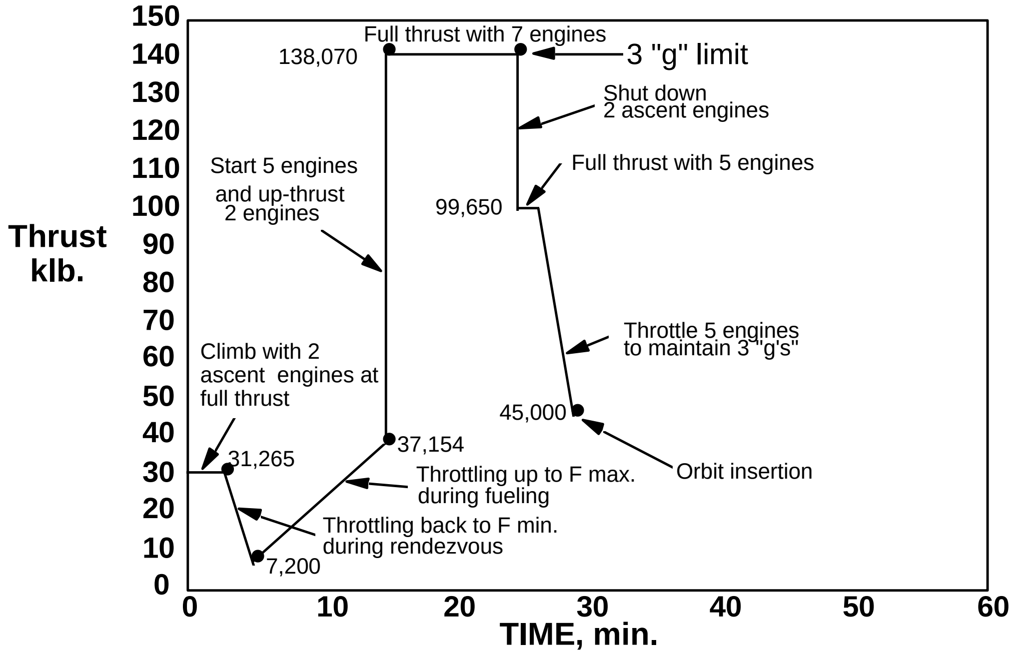


Figure 5. Black Horse Type Vehicle Thrust Profile[53]

Excursions

Several variations of the above program are possible, ranging from a quick-start effort maximizing use of off-the-shelf components to an elaborate series of experiments building on a basic effort.

Quick Start. Two of the long-lead items for the X-program are the airframe and the engines. Key questions include the aerodynamic properties of the vehicle, refueling procedures, and reentry characteristics. A large portion of the test program could be conducted with a nonorbit-capable vehicle, especially if that vehicle could be upgraded later to achieve orbit.

There is some evidence to suggest that such a program could be put together without first creating a paper mountain of design studies. Burt Rutan (of *Voyager* fame) has taken the initiative to design a composite airframe for a Black Horse vehicle.[54] This or a similarly entrepreneurial design could form the basis for a prototype TAV.

Initially, the vehicle could use spare AR-2 engines (used on the NF-104-D, nine are government-owned and currently in storage at Rocketdyne). Production of additional AR-2 engines would be relatively inexpensive. Seven of these engines, operating at full thrust, would be adequate to carry out full refueling tests, all atmospheric flight and a large portion of the suborbital flight test program. Since the number of engines is the same as in the basic Black Horse design, no major airframe changes would be needed to pull the AR-2s and replace them with more capable engines when the latter become available. The new engines would permit further expansion of the flight envelope to include orbital operations.[55]

Avionics, landing gear, crew equipment, and so forth could be borrowed from other programs or taken from stock (as was done on the X-29 and X-31) and replaced with more capable subsystems as needed or desired.

Fuel Enhancements. Historical experience with kerosene-fueled rockets and preliminary theoretical analysis suggest that the engines of a Black Horse vehicle, if properly designed, should be able to burn almost any kind of hydrocarbon fuel. Initial experimentation could focus on the specific-impulse-boosting properties of additives such as quadricyclene. Later experiments could examine the effects of using higher-density fuel such as JP-10, and even lower-quality fuel (e.g. for austere-field operations). Long-term experiments could explore the use of metastable or other exotic fuels as these become available.

Improved Structures. If the initial airframe is not a composite structure, a later Black Horse X-vehicle will want to test such a structure (every pound of reduced structural weight is an additional pound for available payload). In fact, such a structure is not only desirable from a weight standpoint, but from a thermal one: composites can handle greater thermal loads than aluminum, thus simplifying the thermal protection problem. As mentioned above, even a full composite airframe may be a near-term capability.

Alternative Engines. Aside from upgrading with higher-performance conventional rocket engines, a Black Horse TAV offers an attractive test bed for other propulsion concepts. One example of this is a Martin Marietta ducted rocket, which could be mounted on the rear of the airframe between the vertical tails.[56] The reason for considering an engine like this is twofold: first, although any airbreathing system has diminishing returns at high speeds, a ducted rocket could provide both a performance boost at lower altitudes and economize on the use of oxidizer. Second, because of the ducting effect, such a rocket would be less noisy (much as a turbofan is less noisy than a turbojet), a significant potential benefit for both future commercial operations and expanded use of military airfields in peacetime.

Lob/Toss Launch. One way to increase the amount of payload is to use the TAV as a first stage, and lob an upper stage at the peak of a suborbital trajectory. Experimentation with this kind of release and launch could be added to an X-program at any time.

Weapons Delivery. Weapons delivery could be similar to the lob/toss launch of a satellite, but with the intention of the payload reentering the atmosphere. Most of the weapons described earlier in this paper could be developed and tested using the X-vehicle.

Larger tanker/higher fuel transfer rate/dual propellant transfer. Since the initial Black Horse design was sized around the maximum single-ship KC-135 offload, a larger available propellant offload would allow a larger, more capable Black Horse type vehicle. Higher fuel transfer rates through improved pumps and/or larger transfer tubes would mean less time on the boom and ease any aerial refueling problems. Dual propellant transfer (not impossible, since hydrogen peroxide and JP do not spontaneously combust, but not a trivial problem either) would allow extended operations aloft, repeated access to orbit, or returns from long-range suborbital missions without landing.

Transatmospheric Vehicle-to-Transatmospheric Vehicle Refueling. This is another method to increase payload capacity or to provide the fuel needed to take a given payload beyond LEO (even to the moon). "Buddy tanking" of TAVs offers the prospect of very high altitude and high speed refueling. The required testing could be accomplished after initial program goals have been met.

Carrier Vehicles. Some scenarios may favor launching the TAV from a carrier vehicle; indeed this is the more traditional design. Use of a proven "orbiter" (the Black Horse) could simplify the overall system development program if a decision is made to develop the carrier vehicle.

Unmanned Operations. Once the performance characteristics of the TAV are well known and tested throughout the flight envelope, a program could test an unmanned flight control system to include the aerial refueling of the vehicle. This would directly support the development of uncrewed operational variants of the TAV for missions not requiring man in the cockpit.

Attachment H

Black Horse Operating Cost Estimates

Although SPACECAST is not necessarily constrained by cost issues, the fact that a major problem with spacelift systems is their cost, and the fact that reusable vehicles have often claimed extremely good recurring cost-per-pound to orbit numbers, demand that this paper at least explain the basis for the estimate of Black Horse operating costs. Note that this illustration makes no attempt to estimate system acquisition or total life cycle costs at this point; it is solely intended to show a credible basis for the operating cost estimates. The cost model is derived from the actual operating cost data of the SR-71.[57] The basic assumptions are as follows:

- 385 personnel (crew, maintainers, administrators, etc.)
- basic payload handling, similar to SR-71 mission system processing, is included
- 8 TAVs and 8 supporting tankers
- Each vehicle flies once per week; 400 total sorties per year
- Base/site operations and maintenance are $10M per year
- Additional site maintenance per flight is $25,000
- Overhead cost per person is $130,000 per year
- Propellant cost is $0.20/lb for JP-5, $0.68/lb for H_2O_2
- 21,000 pounds of fuel are used per sortie (not including tanker)
- 155,000 pounds of oxidizer are used per flight

The table below shows the cost-per-pound to orbit using the above assumptions and varying first the amount of payload carried, then using the baseline payload but a smaller manning requirement.

	Baseline	Large Payload	Medium Payload	Small Crew	Few Flights (100/yr)
Number of people	385	385	385	200	200
Ops cost multiplier	2.37	2.37	2.37	1.82	4.28
Payload per flight (lb)	1,000	5,000	3,000	1,000	1,000
Total lift per year (lb)	400,000	2,000,000	1,200,000	400,000	100,000
Personnel cost per year	$50,050,000	$50,050,000	$50,050,000	$26,000,000	$26,000,000
Propellant cost per year	$43,840,000	$43,840,000	$43,840,000	$43,840,000	$10,960,000
Total ops cost (incl base)	$103,890,000	$103,890,000	$103,890,000	$79,840,000	$49,960,000
Propellant cost per flight	$109,600	$109,600	$109,600	$109,600	$109,600
Personnel cost per flight	$125,125	$125,125	$125,125	$65,000	$260,000
Total cost per flight	$259,725	$259,725	$259,725	$199,600	$469,600
Cost-per-pound in orbit	$259.73	$51.95	$86.58	$199.60	$469.60

The scenarios above do not explore the entire range of possibilities, but several observations are possible even from this limited sample. First, this system is not cheap to operate relative to aircraft; in fact the numbers are comparable to SR-71 operating costs (often quoted as about $100,000 per flight hour). The cost-per-pound to orbit, however, even under fairly pessimistic assumptions (smallest payload, relatively few flights, high nonflying operations cost), is still quite low. Perhaps this shows just how expensive our current space operations really are (at $10,000 per pound to orbit and up), and how large the potential for improving that figure is with reusable launch vehicles.

The table also highlights the fact that, even with a modest increase in payload capability from the X-vehicle to an operational system, cost-per-pound to orbit can shrink dramatically and the number of tons placed on orbit in a year gets quite large. A redesign of satellites (smaller and/or modular systems, design for shorter lifetimes) and a new concept of space operations to take advantage of this new means of space access (tailored missions, surge, and responsiveness) would offer both further cost savings and tremendous improvements in the operational utility of space.

Notes

[1]The name Black Horse has multiple origins. It is first a tribute to the British Black Arrow and Black Knight programs, which demonstrated the basic propellant concept many years ago. The name also is a link to the SR-71 Blackbird, which provides the tanker aircraft and the basis for the operations cost model. These connections are explained in more detail later in the paper. The Horse part of the name honors an animal that has carried cargo and people in peace and in war. Finally, Black Horse sounds a lot like dark horse, which this system certainly is in the launch systems race.

[2]In honor of the first aircraft to demonstrate aerial refueling. Thanks to Dr F.X. Kane for reminding of us the lineage of experimental programs and for suggesting this name.

[3]Drawing from a conceptual study done by WJ Schafer and Associates and Conceptual Research Corporation for Phillips Laboratory, January 1994.

[4] For example, much monolithic satellite design (sizing, folding/deployable elements and so forth) is based on making maximum use of a single launch vehicle envelope. In contrast, under this approach, a pre-wired structure, solar panels, subsystem modules and payload modules could be designed with relatively simple, quick connect interfaces (work on the space station assembly process would probably be used here) for manual or automated assembly. Active structural control would ensure that necessary alignment tolerances were met after assembly.

[5]See, for example, Air Force Mission Need Statement 202-92, Military Aerospace Vehicles.

[6]US Air Force Space and Missile Systems Center (SMC/XR) "Visions" study, for example. Almost all space panels conclude that spacelift is the critical element in developing space applications.

[7]Essentially, all of the White Papers in SPACECAST have assumed more routine, or at least affordable, access to space as a prerequisite for their implementation.

[8]The Hon Sheila E. Widnall, Secretary of the Air Force, speech to the National Security Industrial Association, 22 March 1994.

[9]Ibid. This situation is often referred to as "the tyranny of the payload."

[10]Prepared statement of Gen Charles A. Horner, CINC United States Space Command to the Senate Armed Services Committee, 22 Apr 93

[11]DoD Space Launch Modernization Plan, April 1994.

[12]Ibid. See also the SPACECAST 2020 White Paper on Space Operations and Space Traffic Control
[13]See the Vice President's Space Advisory Board, "The Future of the US Space Launch Capability: A Task Group Report", November 1992 (the Aldridge report) for cost goals for Spacelifter. Other sources (cited in Air Force Institute of Technology alternative lift briefing) generally give higher costs-per-pound to orbit for the small expendable lift systems that for large expendables.
[14]Aldridge report, NASP studies, Delta Clipper studies.
[15]E.C. Aldridge interview with author during first Advisory Group visit, January 1994.
[16]For example, DARPA's Advanced Space Technology Office has produced several articles on the capabilities, operational benefits, and potential cost savings of small, modular satellites.
[17]Horner testimony (see note 8), Widnall speech (note 6)
[18]Operations costs for Kennedy Space Center and Vandenberg run into billions of dollars per year, and it takes weeks to months to refurbish a launch pad following a launch for the next event.
[19]Clapp and Hunter, A Single Stage to Orbit Rocket with Non-Cryogenic Propellants
[20]McDonnell Douglas Diagram in Bill Sweetman, *Aurora: The Pentagon's Secret Spy Plane,* (Osceola, WI: Motorbooks International Publishers and Wholesalers, 1993).
[21]Ibid.
[22]"Advantages of Hydrogen Peroxide as a Rocket Oxidant," by David Andrews, Journal of the British Interplanetary Society, July 1990. See also, Project RAND, "Propellants for Supersonic Vehicles: Hydrogen Peroxide", RA-15046, Douglas Aircraft Company, August 12, 1947.
[23]Capt M. Clapp, DC-X flight crew member, interview with author January 1994.
[24]Although more detailed study is needed, the relatively low take off weight of the TAV described in this paper should result in a noise level similar to that of an F-15 in afterburner. Noise is related to exhaust jet speed and surface area, and while the TAV exhaust is about twice as fast, the area should be less.
[25]Of course, this technique is not limited to horizontal takeoff and landing vehicles; it was even considered for the Apollo mission, according to Dr F. X. Kane. However, a winged horizontal takeoff and landing vehicle offers the best performance match to existing (and hence the least expensive option) tanker assets.
[26]For NASP, structural design and materials problems due to sustained hypersonic airbreathing flight, fuel tankage, and engines. For carrier/orbiter concepts, a large, expensive, unique carrier vehicle with considerable development costs of its own.
[27]The environment a TAV must operate in is no more hostile to human life than the environment a U-2 or TR-1 routinely operates in.
[28] Conversation with Capt M. Clapp, USAF Phillips Lab, May 1994. The number comes from the rule of thumb that landing gear will weigh approximately 3 percent of gross takeoff (or landing, whichever is greater) weight.
[29] Ibid.
[30] Full details are contained in the paper and briefing from WJ Schafer and Associates and Conceptual Research Corporation, January 1994
[31]Ibid.
[32] Briefing from USAF Phillips Lab (Capt Clapp) to SPACECAST, 29 Apr 1994. Performance numbers and flight profiles were validated using NASA's "Program to Optimize Simulated Trajectories" (POST).
[33]Project Forecast II, (June 1986); Mission Applications Document, (22 July 1990); and Force Applications Study, (13 June 1991)
[34]T.O. 1-1M-34, SUU-64/B, Tactical Munitions Dispenser, 31 May 1991, 1-110.
[35]DAS-TR-89-1, *Comprehensive On-Orbit Maintenance Assessment (COMA) (*Kirtland Air Force Base, NM; Directorate of Aerospace Studies, 31 March 1989), 61.
[36]Op. Cit, note 23
[37] From a Rocketdyne briefing on the NF-104D program, undated, on file at Phillips Laboratory.
[38]Paper and briefing from WJ Schafer and Associates and Conceptual Research Corporation, January 1994.
[39]The design assumes a 98% efficient injector, for example. current engine designs (the space shuttle main engine, for example) achieve 99.8% efficiency.
[40] A ducted rocket uses the combustion and exhaust mechanisms of a conventional rocket, but gets its oxidizer (atmospheric oxygen) by using air intakes instead of an on-board supply. This has particular advantages at lower altitudes and speeds. Martin Marietta, among others, has design concepts for this type of system.
[41]Based on Phillips Laboratory parametric studies.

[42]AFSC/DAS study.
[43]According to figures in the KC-135Q "Dash-1," the tanker will be volume (not weight or center of gravity) constrained in the amount of hydrogen peroxide it can carry. This results in a maximum load of about 147,000 pounds. The entire amount can be transferred in approximately 11 minutes. The KC-135Q offload rate is 1200 gallons per minute, and since hydrogen peroxide (at 11.92 pounds per gallon) is substantially denser than jet fuel, this results in a propellant weight transfer of about 14,300 pounds per minute.
[44]Clapp and Hunter. Page .
[45]Paper and briefing from WJ Schafer and Associates and Conceptual Research Corporation, January 1994.
[46]Memo from Phillips Lab XPI, dated 20 March 1994
[47]See, for example, the briefing “Economic Considerations of Hypersonic Vehicles and Space Planes,” by G. Harry Stine and Paul C. Hans, The Enterprise Institute, 1990.
[48] Aerial refueling is now as common in military air operations as a beverage service is on commercial flights, and it is usually (and rightly) thought of as a way to extend the range and endurance of aircraft. What hasn’t been fully appreciated was that this has also affected the design of aircraft, i.e. a fighter can have global range--if it can refuel often enough--without carrying all that fuel at takeoff. What’s new is applying this concept to a space-faring vehicle. For the concept to become commercially viable, commercial operators will also have to embrace air refueling as a routine operation, though this should be no greater leap than the first commercial aircraft or the first commercial jets.
[49]Boyd lecture to SPACECAST, October 1993.
[50]Force Applications Study, 13 June 1991.
[51]Figure from Phillips Laboratory briefing on the Black Horse concept.
[52]Op. cit., note 32.
[53]Figure from op. cit., note 33.
[54]Capt M. Clapp Interview with author , USAF Phillips Lab, 5 April 1994.
[55]Ibid.
[56]Ibid.
[57]Max Hunter, "Experimental Space Craft," *Journal of Practical Applications in Space*, Fall 1993.